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INTERNATIONAL NUCLEAR DATA COMMITTEE

IAEA Advisory Group Meeting on

NUCLEAR AND ATOMIC DATA FOR RADIOTHERAPY
AND RELATED RADIOBIOLOGY

in co-operation with the Radiobiological Institute
of the Division for Health Research TNO

16 - 20 September 1985
Rijswijk, the Netherlands

SUMMARY AND RECOMMENDATIONS

Edited by

K. Okamoto
Nuclear Data Section
International Atomic Energy Agency

November 1985

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CORRIGENDA

Page 9 1st para, lines 3+4: amu should read u

at the bottom: 2. Measurements for each Heavy Ion in 50 MeV/amu
should read 50 MeV/u

last line: helim should read helium

Page 13 2nd para, lines 7 to 11 (3 sentences): It will be necessary
.....for calculations. Thus some data are determin-
ing doses. There are requirements nuclear data. This
should read: There are requirements for both atomic and nuclear
data. Particularly for nuclear data it will be necessary to fit
theoretical models to data at selected energies and to use these
models to generate a sufficient data set for calculations. Thus
some data are needed primarily to establish the parameters of
these models while others are needed for direct use in
determining doses.

Page 18: 1st para, line 1: evelopment should read development

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Abstract

The IAEA Advisory Group Meeting on "Nuclear and Atomic Data for Radiotherapy and related Radiobiology" was held at Rijswijk, the Netherlands, from 16 to 20 September 1985, in co-operation with the Radiobiological Institute TNO.

The meeting participants reviewed the current and future requirements on nuclear and atomic data for radiotherapy and radiobiology, identified data requirements and their priorities, and issued a number of specific recommendations for future technical work in nuclear and atomic data required to establish a more solid nuclear physics foundation of radiotherapy and related radiobiology. The recommendations in this report are directed to three areas, namely beam production and field description, dosimetry, and interpretation and optimization of biological effects. The final proceedings will be issued as an IAEA publication in 1986.

FOREWORD

The Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and related Radiobiology was held at TNO, Rijswijk, the Netherlands, from 16 to 20 September 1985 in co-operation with the Radiobiological Institute TNO, as recommended and endorsed by the International Nuclear Data Committee. The meeting was attended by 35 scientists from 9 Member States and three international organizations.

There are strong demands among physicists engaging in radiotherapy and related radiobiology for more accurate nuclear and atomic data for their own research. Continuous reviews of the requirements for nuclear and atomic data and of the determination of the data uncertainties in this field are required.

Since the initial announcement of this meeting the Agency has received many letters of encouragement and support from physicists working in nuclear particle radiotherapy. This type of data meeting in the field of radiotherapy and related radiobiology had never been held before, and all participants in the meeting expressed their appreciation for this timely arranged meeting and hoped that this activity would continue in the Agency.

The meeting had the following specific objectives:

- to make an inventory of the available knowledge on nuclear and atomic data sets relevant to radiotherapy and related radiobiology,
- to identify and specify further needs for nuclear and atomic data and their accuracies,
- to stimulate new experimental and theoretical work to fill the identified gaps in nuclear reaction, decay and atomic data, and
- to formulate specific technical recommendations for future work.

This report contains the summary and recommendations of the meeting and it is issued for the purpose of publicizing widely the data requirements in radiotherapy and related radiobiology. The full meeting proceedings are to be issued in the IAEA Publication next year.

The Scientific Secretary of the meeting wishes to express his appreciation to the Division for Health Research of the TNO for its kind arrangements and assistance in hosting the meeting. Particular gratitude goes to Dr. J.J. Broerse and the staff of the Radiobiological Institute TNO for their devotion to the organisation of the meeting and for their excellent hospitality.

K. Okamoto
Scientific Secretary
of the Meeting

1. Introduction

On the basis of the responses to inquiries received from international experts in the area of radiation research it must be concluded that there is still a strong need for additional and more accurate nuclear and atomic data. Such data are required e.g. to enable accurate radiation transport calculations in radiotherapy and radiation protection, to enable a better assessment of the primary molecular changes produced by the interactions of different relevant radiation fields with biological matter and thus to improve the physical basis for a better understanding of important radiobiological mechanisms in radiotherapy as well as in radiation carcinogenesis.

There is a number of evident reasons for the needs of improved nuclear and atomic data sets. In radiotherapy, e.g. recent progress uncovered the present inadequacy of these data sets for sufficiently accurate transport calculations in physical treatment planning to supplement and optimize medical therapeutic procedures. Clinical trials performed recently with a mixed schedule of neutron and photon irradiations seem to be promising; here an identification of optimum physical beam parameters is urgently needed. For future neutron therapy applications also very fast neutron beams (e.g. from high energy cyclotrons using the p+Be reaction with proton energies up to 70 MeV) will be used, which should have physical characteristics comparable to those of megavolt photon beams. Also here adequate data sets for transport and efficiency calculations are needed.

In addition, charged particles are already or will soon be applied for radiotherapy at a number of places around the world: Pion therapy at Zürich (Switzerland), Vancouver (Canada) and probably at Kansai and Kanto districts (Japan); heavy ion therapy at Berkeley (USA) and Uppsala (Sweden). Accompanying quantitative radiobiology also based on physical transport and charged particle track structure calculations is needed to investigate the biological effectiveness of these new beams.

For the optimization of diagnostic X-ray fields (maximum diagnostic information at minimum radiation hazards) the biological effects of low energy photons have to be analyzed in more detail since some theoretical and experimental evidence indicates that their radiation hazards might be larger than those of higher energy photons. Incorporated beta-emitters like H-3, C-14, Sr-90, Te-99, I-125, etc. could also have physical characteristics which might lead to relative biological effectiveness for relevant endpoints higher than one. Furthermore, our knowledge on the microdosimetry of incorporated alpha-emitters like radon, radon-daughters or other nuclides from nuclear facilities urgently needs improvement since these radionuclides usually lead to extremely heterogeneous dose patterns on a sub-organ scale.

Finally, in radiation biology it has been realized more and more that a better knowledge of the detailed microscopic topography of physical interaction processes on a sub-cellular level is an indispensable prerequisite for further improvements in our understanding of mechanisms of biological radiation effects. To be able to provide such physical information, e.g. by Monte Carlo track structure simulation programs, first the scarce existing cross section data base has to be improved.

2. Meeting organization

After extensive preparations the Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and related Radiobiology was convened at Rijswijk, the Netherlands during the week of 16 to 20 September 1985.

The meeting programme was formulated on the basis of advice received from an organizing committee for this meeting composed of the following scientists:

J.M. Bradbury (USA)	H. Liskien (CBNM/EC)
J.J. Broerse (The Netherlands)	H.G. Paretzke (FRG)
W.G. Cross (Canada)	K. Okamoto (IAEA, Scientific Secretary)

The organizing committee recommended that the following topics should be covered, and based on these topics the speakers for each topic had been selected:

Topics of the Meeting

Introduction:

- Scope of the programme of the IAEA Nuclear Data Section
- Status of nuclear and atomic data from the producers' point of view
- Inventarization of nuclear data for interactions with biological material
- Basic data on nuclear decay schemes

Applications:

- Practical aspects of nuclear particle dosimetry
- Protocols for nuclear particle dosimetry
- Biophysical basis for biological effects

Beam production:

- Neutron energy spectra of p+Be and d+Be reactions
- Differential pion production cross sections

Macroscopic dosimetry:

- Cross sections for neutron interactions with tissue constituents
- Neutron-induced secondary charged particle spectra, and kerma calculations
- Stopping power
- W values

Interaction of (secondary) charged particles:

- Type and energy spectra of secondaries from interactions of pions
- Type and energy spectra of secondaries from interactions of heavy ions
- Fast neutron and pion interaction data from low pressure proportional counters

Charged particle track structure:

- Range and energy loss of electrons
- Scattering cross sections of electrons and heavy ions
- Parameters characterizing charged particle track structures

Twenty seven papers were presented at six plenary sessions. During the last 2 days of the meeting the participants split into the following three groups:

WG-1: Beam production and field description

WG-2: Dosimetry

WG-3: Interpretation and optimization of biological effects

The summary and recommendations of Working Groups were collected by two group leaders in each group. The Working Group reports are reproduced in the summary report of the meeting, as follows.

SUMMARY AND RECOMMENDATIONS

Working Group I

BEAM PRODUCTION AND FIELD DESCRIPTION

Group Leaders: D.K. Bewley
J. Bradbury

Members: H. Blattmann
D.E. Bonnett
M.A. Chaudhri
R.T. Devine
G. Dietze
T. Inada
A. Paulsen
J.R.H. Smith
K.R. Smith
T. Takahashi (part time)

NEUTRONS

I. BACKGROUND

Until now it has not been possible to give neutron therapy with the same technical efficiency as is usual with X-ray therapy. In order to do this, new neutron generators are now coming into operation at higher energies with isocentric mountings and adjustable collimators. The neutron beams are generally produced by the reaction of protons in the range 30-70 MeV on targets of Be. Li is an alternative material and neutron and gamma-ray production in backing materials such as C, H₂O and Cu are also important. More detailed information is needed on the neutron spectra produced from these materials.

The design of the neutron head is at present largely based on experimental measurements. Adequate nuclear data would enable the design to be optimised theoretically.

The distribution of absorbed dose (neutrons and gamma rays) in the patient is calculated from experimental measurements in tissue-equivalent materials. Additional nuclear data would enable the distributions of absorbed dose and neutron spectra in the patient to be calculated. This would be useful for the optimisation of treatment planning and for the choice of suitable dosimeters to be used on the patient.

II. SPECIFIC REQUIREMENTS

(i) Neutron Production

Compilation and measurement of neutron spectra down to 500 keV as a function of angle, for proton bombardment of Be at energies up to 100 MeV*. Thin-target neutron production cross-sections for protons on Be would be of particular value.* Information is also needed on associated gamma-ray production.

Other important materials, but at a lower priority, are C, D, O, Li and Cu.

(ii) Head Shielding

For design of head shielding and collimators there is a need for data on the cross-sections of Fe, C, W and Cu of which Fe* should have the highest priority. Cross-sections are needed up to 100 MeV including production and angular distribution of secondary (n,xn) neutrons and associated gamma radiation.

(iii) Distribution of absorbed dose and spectra in the patient

Experimental spectrometry by the scintillation method in a tissue-equivalent medium needs additional information on cross-sections of carbon up to 100 MeV for neutron-induced reactions.*

Threshold detectors represent another method of neutron spectroscopy. There are standard detectors for determining spectra up to about 20 MeV but their response to higher energy neutrons is usually unknown. An evaluation of existing data is needed, both with respect to these detectors and to others needed to measure the high energy component. Such an evaluation will show what new measurements are necessary in the neutron energy range from 20-100 MeV. The influence of photonuclear reactions must be borne in mind.

For calculation of transport in the patient it is necessary to extend up to 100 MeV cross-section data of the elements present in tissue. The most important are oxygen* and carbon*. N, P and Ca are of lower importance.

* Indicates high priority

PROTONS

I. BACKGROUND

At present no facilities exist that have been specifically designed for proton therapy. Optimum design and usage of a dedicated facility require a substantial nuclear data base only part of which is currently available. Techniques for generating proton beams of about 250 MeV are well understood. For use in radiotherapy these beams are modified in spatial and momentum distribution by devices such as energy degraders, ridge filters, scatterers, etc. in which the protons may undergo elastic (p,p) and inelastic (p,p') scattering, (p,n), (p,d), (p,t), (p,He³) and other (p, spallation) reactions which affect the radiation field through changes in the proton phase space and through the introduction of neutrons and ions. In tissue or tissue-like materials the same reactions can occur. To correctly calculate doses for predictive or archival purposes, to the desired accuracy of < 5% (particularly difficult near the edges of fields) the effects of these reactions must be included. In addition, measurements of LET distributions and RBE's in the proton stopping region have indicated the presence of heavily ionizing particles which quantitatively cannot yet be explained.

II. SPECIFIC REQUIREMENTS

Cross-section data for elastic and inelastic scattering of protons in appropriate elements are sparse but probably adequate below about 65 MeV.

Additional data (energy spectra and angular distributions) are needed in the range 50 to 250 MeV. The (p,n) reaction has been well-studied for selected elements such as Be, Li but not for all of the elements listed below. Measurements of the neutron energy spectrum and angular distribution are required for proton energy $E_p > 50$ MeV although for elements heavier than C intra-nuclear cascade calculations exist in this energy range which are probably adequate. For the reactions yielding hydrogen and helium isotopes and heavier fragments only very limited data are available and measurements need to be made for the relevant targets at several proton energies to check the intra-nuclear cascade calculations.

1. Materials of Interest

Beam shaping devices: Al, Cu, Fe, Pb, W

Target volume: H, C, N, O

2. Cross Sections - Energy and Angular Distribution

2.1 Elastic scattering	$E_p = 50 - 250$ MeV
2.2 Inelastic scattering	$E_p = 50 - 250$ MeV
2.3 (p,n)	$E_p = 50 - 250$ MeV for H,C,O only
2.4 (p,d), (p,t), (p, ³ He)*	$E_p = 100 - 250$ MeV
2.5 (p,spallation)*	$E_p = 200 - 250$ MeV

* Indicates high priority

HEAVY IONS

I. BACKGROUND

The heavy ions considered for use in radiotherapy include He, C, Ne, Si and Ar. At Lawrence Berkeley Laboratory (LBL), USA, the production and acceleration of these ions have been extensively studied and this area probably needs little attention in the near future. Recent proposals by

groups at LBL and National Institute of Radiological Sciences (NIRS), Japan, provide descriptions of the state-of-the-art technology that is available for a dedicated facility.

The nuclear data needed to adequately describe the radiation field produced by a beam of heavy ions are not yet available. The appropriate energy ranges are He-250 MeV/amu, C-400 MeV/amu, Ne-800 MeV/amu, Si-800 MeV/amu, Ar-800 MeV/amu, where some limitations in accelerator capability have been assumed. The heavy ion beam may pass through devices such as energy degraders, scatterers, ridge filters, etc. before reaching the region containing tissue or tissue-like material.

II. SPECIFIC REQUIREMENTS

It is necessary to have data for the following reaction mechanisms: 1) charge-state redistributions, 2) scattering, 3) projectile fragmentation, and 4) direct interactions. Since the ions remain fully stripped until very nearly stopped, mechanism 1) probably needs no further work. Models exist for mechanisms 2), 3), and 4) but the predictions in general do not agree with the limited experimental data available at the desired level of accuracy. Much more experimental data are needed both to generate improved models and permit dose calculations. In addition to cross-section data further development of transport codes in thick targets should be encouraged.

1. Materials of Interest

Beam shaping devices: Al, Cu, Fe, Pb, W

Target volume: H, C, N, O

2. Measurements for Each Heavy Ion in 50 MeV/amu Steps

2.1 Excitation functions and velocity distributions for projectile fragmentation.

2.2 Energy spectra, angular distributions, and multiplicity of neutrons and hydrogen and helium isotopes.

NEGATIVE PIONS

I. BACKGROUND

1. Beam Production

The nuclear data base for the production of pions by protons and electrons is sufficiently extensive to permit facility designs. Since deuteron accelerators are feasible and (d, π^-) production cross-sections may be relatively large, some cross-section data for the production of π^- from Be and Mo by deuterons in the energy range 1-2 GeV region would be desirable.

2. In-Flight Processes

Multiple scattering and elastic scattering of pions in tissue, degrader materials and collimation systems are known with adequate accuracy. More data on inelastic scattering of pions in tissue constituent elements might be of use. In-flight absorption cross-sections are known for carbon but are not known for important elements such as oxygen, nitrogen, calcium and aluminium.

3. Pion Atomic Capture

Pion atomic capture probabilities in tissue cannot, at present, be predicted due to the presence of chemical effects on capture. Although modeling of capture in exclusively low-Z materials looks promising, to understand pion capture in tissue the effects of the presence of high-Z elements need to be known as does the influence of different chemical environments in aqueous solutions. This information is necessary for the prediction of pion dose in different tissue types. Measurements of pionic X-ray spectra of different tissue types are important for both checking atomic pion capture models and characterizing the dose deposited. Muon capture data are also of relevance for understanding the capture process and should be taken into consideration.

4. Pion Nuclear Absorption

The secondary charged particle and neutron spectra from pion nuclear absorption by major tissue constituents need to be known. Data for charged particles from carbon, oxygen and calcium are available although the energy balance of the charged particles and neutrons from these elements are not quite consistent with energy conservation. The charged particle spectra for other elements such as nitrogen, phosphorous and iron are essential. Neutron spectra for carbon, oxygen and nitrogen have also been measured but there is strong disagreement between older and newer experimental measurements. The recent measurements agree better with energy conservation and show consistency with each other. Complete data for neutron spectra up to 140 MeV but with special emphasis on the low energy portion are required for carbon, oxygen, nitrogen, calcium and phosphorous. Neutron spectra from elements are far more predictable than the charged particle spectra and so it may not be necessary to measure them for minor, but important constituents such as iron.

5. Beam Contaminations

All pion beams contain muon and electron contaminations. The behavior of the electrons is believed to be well understood. The scattering and absorption of muons is known sufficiently well. However, Auger electrons which are produced both by muon and pion atomic capture may contribute to the biological damage, and their production cross sections are not sufficiently well known.

II. SPECIFIC REQUIREMENTS (* indicates high priority)

1. Materials of Interest

Beam shaping devices: Al, Cu, Fe, Pb, W

Target volume: H, C, N, O

2. Measurements

2.1 In-flight absorption of pions (particularly in Al)

- 2.2 Capture probabilities in different tissue types and data for extending pion capture models to materials containing high-Z elements and aqueous solutions.*
- 2.3 Pion absorption data including charged particle spectra for C, O, Ca, N^{*}, and P^{*}, and neutron spectra for C, N, O, Ca, P.
- 2.4 Auger electrons from pion capture.

Working Group II

DOSIMETRY

Group Leaders: W.G. Cross
H.G. Menzel

Group Members: D.J. Brenner
J.J. Broerse
J.J. Coyne
V.D. Huynh
B.J. Mijnheer
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Zhou Enchen

I. INTRODUCTION

The Working Group considered the requirements for data used in determining tissue doses in therapy with neutrons of energies up to 100 MeV, protons up to 250 MeV, pions and heavy ions. As a starting point for deciding accuracy requirements, the statements in ICRU reports 24 and 28 that it is desirable to determine doses in soft tissue with an overall absolute uncertainty of $\pm 5\%$ and a precision of $\pm 2\%$ were noted. This overall accuracy implies that the separate contributions of stopping power ratios, W values and kerma ratios in ion chamber materials and tissue should be known with absolute uncertainties of about $\pm 2\%$.

These requirements were written particularly for routine dosimetry with photons, for which the techniques are well-established and adequate data are generally available. While this accuracy is a reasonable goal for newer types of therapy, it is recognized that it may not be practical to achieve this goal for many years. That is because both compilation and evaluation of existing data and measurement of new data are required. It will be necessary to fit theoretical models to data at selected energies and to use these models to generate a data set sufficient for calculations. Thus some data are needed primarily to establish the parameters of these models while others are needed for direct use in determining doses. There are requirements for both atomic and nuclear data. Application of these data for determining doses of course depends on knowledge of the radiation spectrum at the point of interest.

II. SPECIFIC REQUIREMENTS

II.1 Nuclear data

The quantity of nuclear data which could advantageously be used in helping to determine tissue doses in radiotherapy is extremely large. It includes all cross-sections, secondary particle spectra and angular distributions from the interaction of high energy neutrons, protons, pions and heavy ions in all tissue elements, as well as data of importance in determining the responses of detectors used in radiotherapy. Since it is impractical to measure all these data within a sufficiently short time to affect clinical trials of these new models of therapy, the Advisory Group recommends that initial efforts be concentrated on to selected data as described below.

A. Neutron Radiotherapy

The most immediate requirement is for the compilation and evaluation of all existing data for interactions in C and O of neutrons from 10 MeV to 100 MeV and for construction of a data file based on a standard (e.g. ENDF/B) format. The overlap of this file with existing data libraries in the energy range 10-20 MeV is proposed because of apparent important discrepancies in C data that affect the calculation of kerma factors. Initially, at least, this file may be limited to data that can contribute to the calculation of kerma factors or to neutron transport calculations.

A second requirement is for the evaluation of existing neutron kerma factors in C or O at energies up to 100 MeV.

New measurements are required for the following neutron data either because only insufficient data exist or because there are serious discrepancies in these data. The most urgently required data are marked with an asterisk.

- a)* Differential cross-sections for elastic scattering from C or O between 15 and 20 MeV and at some energy between 50 and 100 MeV. The 15-20 MeV data are required because kermas calculated

from existing scattering data between 21 and 26 MeV do not match those used for ENDF/B data.

- b)* The cross-section and alpha particle spectrum for the $^{12}\text{C}(n,n')3\alpha$ reaction between threshold and 25 MeV to resolve existing discrepancies in cross sections and kerma factors.
- c)* Double differential cross-sections for production of various charged particles at an energy near 20 MeV in C and O to provide an additional energy at which intranuclear cascade calculations can be tested.
- d) Charged particle production cross-sections and energy spectra for O between 15 and 20 MeV for kerma calculations in this energy range.
- e) Photon production cross-sections for C or O from 15 to 100 MeV for estimation of the low LET dose component.
- f) Direct measurements of kerma factors for C, (e.g. by proportional counters or calorimetry) from 10 to 100 MeV. This will provide a valuable check on kerma calculations based on incomplete data.
- g) Cross-sections for (n,xn) activated detectors suitable for radiotherapy applications at energies from 20 to 50 MeV, for spectral measurements.

The absolute uncertainties desired for kermas in C and O are about 3% but it is not certain that it is practical to obtain these.

Since the requirements for accuracy on C or O data used to determine the ratio of kermas in tissue and tissue-equivalent plastic would be greatly reduced if the composition of TE chambers were much closer to that of tissue, the search for more suitable TE materials should continue.

Data for therapy with protons, pions and heavy ions have been considered previously. The same types of nuclear data are required for dosimetry.

B. Proton Therapy

The main requirement is for the cross-sections of C and O and for spectra of neutrons, protons, deuterons and alpha particles produced during the slowing down of protons having initial energies up to 250 MeV in O or C. It may be possible to obtain sufficiently accurate data by calculations using existing nuclear models.

C. Pion Therapy

Cross-sections of C and O and spectra of neutrons and charged particles produced during the slowing down of 100 MeV negative pions in C or O required. There is also a need for information on the influence of molecular structure on pion capture ratios.

D. Heavy Ion Therapy

Cross-sections and spectra of charged particles produced during the slowing down of heavy ions are needed.

II.2 Atomic Data

The most relevant atomic data for dosimetry are W-values and stopping powers. The ICRU report on W-values provides a basis for assessing the present knowledge of W-values of different charged particles in various gases. There is a need for new W-value measurements for all secondaries from neutron and pion interaction with tissue and tissue like materials. In particular for protons from 10 keV and heavier ions from 10 keV/amu (C, N, O, α , d). The gases of interest include N_2 , CH_4 , C_3H_8 , CO_2 , Ar, tissue equivalent gas mixtures (methane and propane based) and air. For dosimetry in proton and heavy ion therapy and radiobiology W-values are also required ions (up to Ar) extending to sufficiently high energies (several 100 MeV/amu).

Theoretical and semi-empirical models should be applied to enable interpolation and extrapolation between and beyond experimentally determined values. Important for practical and theoretical reasons is

the analysis of the validity of the additivity rule. Calibration of ionization chambers in radiation field other than used for therapy (e.g. photon calibration of neutron dosimeters) implies that the uncertainty of W-values ratios is of relevance.

The necessary improvement in the knowledge of stopping powers and stopping power ratios requires new measurements of this quantity for ions in gases and a number of organic components and other solid materials. The energy range of greatest interest is for protons 0.01-10 MeV, for alpha particles 0.01-10 MeV and for heavier particles (up to Ar) 0.1 MeV/u to several 100 MeV/u. The gases of interest are the tissue equivalent mixtures and their constituents air and Argon. The solids include A-150 plastic, perspex, polyethylene and nylon (phantom materials) and for neutron and pion secondaries also aluminium, magnesium, calcium and phosphorous. The evaluation of existing and future data should be based on theoretical models.

In practical dosimetry it is conventional to apply gas-to-wall conversion factors which are equal to the stopping power ratio in case of an ideal Bragg-Gray chamber. For finite size chambers and most radiations, in particular fast neutrons and pions, however, more complex gas-to-wall conversion factors have to be applied. A systematic evaluation of gas-to-wall conversion factors as function of particle energy, detector materials and cavity size is of importance. At present there is a lack of such data in particular for non-homogeneous chambers (e.g. Al-chambers filled with Ar). Gas-to-wall conversion factors can either be calculated from basic atomic and nuclear data or directly measured by comparing absorbed dose measured with a calorimeter and with an ionization chamber made of the same material.

An important dosimetric quantity is the energy spectrum of charged particles in the treatment field. Presently they can only be obtained from calculation, and so should be checked by related calculations and measurements of microdosimetric spectra.

Atomic data are also required to improve our knowledge on the theory of ionization in gases e.g. in order to improve our understanding of recombination processes. This is of relevance for the precision of

measurements and may be useful for obtaining radiation quality information.

Atomic data are also of relevance for the analysis and development of tissue equivalent detector materials. In general, compromises will have to be accepted between practical requirements (e.g. electrical conductivity) and optimum tissue equivalence and between optimum tissue equivalence with regard to nuclear data and to atomic data. In pion dosimetry the particular problem is encountered that local doses are dependent on the structure of molecules because of the dependence of pion capture ratios on the chemical nature of individual tissue and even cell constituents. A solution of this problem requires a detailed study of pion capture ratios for important organic molecules and specific tissues.

Specific dosimetric problems such as measurements with high spatial resolution and in vivo dosimetry require the use of other types of detectors, for instance silicon detectors and TLD doseimeters are applied. There is an obvious need for related nuclear and atomic data.

Working Group III

INTERPRETATION AND OPTIMIZATION OF BIOLOGICAL EFFECTS

**Group Leaders: M. Inokuti
H.G. Paretzke**

**Group Members: M.J. Berger
D.E. Charlton
D.T. Goodhead
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I. INTRODUCTION

During the Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Related Radiobiology it became evident that significant advances have been made in the biophysical modelling and in the understanding of radiation effects. Particularly promising contributions have resulted from recent work on radiation track structure theory. Further progress, however, is severely hampered by the lack of adequate nuclear and atomic data. In view of the large potential of radiotherapy to treat cancer, of the importance of understanding underlying biological mechanisms for the optimisation of therapy and of the development of new therapy modalities, the Working Group recommends the following:

- A) The IAEA establish and maintain a bibliographic service to collect and disseminate relevant nuclear and atomic data as specified in the second section.
- B) The IAEA also establish a coordinated research programme
- to promote the critical evaluation and codification of pertinent data;
 - to foster collaboration between various centers and individual scientists;
 - to stimulate the generation of new data and theoretical approaches.

Liaison and coordination should be maintained with groups which share an interest in these topics (e.g. other groups in IAEA, ICRU, ICRP, national data centers).

II. SPECIFIC REQUIREMENTS

The radiation fields used in radiotherapy and related radiation biology include photons, electrons, neutrons, mesons and fast ions. All of these radiations impart most of their energy predominantly by charged particles, in general and most importantly by electrons. To trace the sequence of the production of secondaries, their interactions and to understand the consequences of these interactions, there is a need for a large variety of nuclear and atomic cross-sections and related physical quantities. Listed below are such cross-sections and quantities which are important but presently either not known, or not sufficiently well known. Items of highest priority are indicated by an asterisk (*).

1. Materials of interest

Condensed phase: Water (*), DNA (*), proteins (*), graphite, N₂, O₂, plastics (aimed at comparison with gases of the same elemental composition), LiF, CaF, Si.

Gas phase: Water vapour, H₂, O₂, N₂, air, TE gas.

2. Cross-sections

2.1 Secondary electron production cross-sections

- for protons and alpha particles, especially below 300 keV (*),
- for heavy ions (C, N, O) (*), energy range 100 keV to 10 MeV.

2.2 Electron elastic scattering cross sections (10 eV - 1 keV).

2.3 Electron inelastic scattering cross-sections (10 eV-1 keV) for ionisation, excitation, dissociation, etc. (*).

2.4 Photoelectric cross-section (100 eV - 10 keV) (*) (e.g. from synchrotron radiation measurements).

2.5 Auger - electron transition rates.

3. Related physical quantities

3.1 Stopping power data

Heavy ions (C, N, O)	100 keV - 10 MeV (*)
Protons	1 keV - 10 MeV (*)
Electrons	500 eV - 100 keV
Alpha particles	50 keV - 20 MeV

3.2 Electron transport below 10 eV (*)

3.3 Track structure quantities (*)

- Yield of ions, excitations, and dissociations (W- and G-values)
- Electron slowing down spectra
- Spectra of imparted energy
- Radial dose profiles
- Dose point kernels, etc.

III. BACKGROUND TO THESE RECOMMENDATIONS

Future advances in radiotherapy will depend to a considerable extent on a better understanding of the underlying mechanisms of radiation action on human cells. Most biophysical models of radiation action now agree that biological effects are strongly influenced by the radiation track structures on a scale of cellular dimensions down to nanometres or even less. Biological evidence suggests strongly that radiation-induced

cell death follows from damage to DNA and possibly associated structures. To test radiation biophysical models, to develop new approaches, and to identify characteristic radiation field properties, it is essential to have accurate descriptions of the pattern of radiation track structures over these dimensions.

Present track structure calculations have mainly been developed for water vapour. Calculations for water in the condensed phase have been limited by the lack of cross-section data. Since water is a major component of cells, serious efforts should be directed to obtaining condensed-phase water data. It is probable that a significant component of radiation damage results from direct action of the radiation on DNA and protein molecules. Therefore it is highly desirable that in future one should also be able to simulate more realistically track structures of relevant charged particles in DNA and associated protein in their cellular environment. This requires a knowledge of cross-sections and related physical quantities detailed above. The activities recommended in the first section will help to obtain them in a reasonable time.

RECOMMENDATIONS AT LARGE

All participants unanimously adopted the following recommendation.

The Advisory Group would like to point out that ordinary scientific education does not put enough emphasis on the knowledge needed for expert evaluation of such nuclear and atomic data.

Therefore and because more active workers are needed in this field, the IAEA might consider an appropriate training programme for young scientists.

IAEA Advisory Group Meeting on
NUCLEAR AND ATOMIC DATA FOR RADIOTHERAPY AND RELATED RADIOBIOLOGY

in co-operation with the Radiobiological Institute TNO

16 - 20 September 1985
Radiobiological Institute TNO
Rijswijk, The Netherlands

PROGRAMME

Sunday, 15 September

20:15 - 22:00 Get-together (welcome drinks and snacks) in the lounge of the Museumhotel, Oude Delft 189, Delft

Monday, 16 September

09:00 - 09:30 Welcome by Prof. Dr. D.W. van Bekkum, director of the Radiobiological Institute TNO, and Dr. K. Okamoto, IAEA, scientific secretary of the meeting.

SESSION I INTRODUCTION

Chairman: J.J. BROERSE

10:00 - 10:30 K. OKAMOTO: Scope of the programme of the IAEA Nuclear Data Section for medical applications

10:30 - 11:10 D.E. CHARLTON: Atomic data required for the calculation of local energy deposition near isotopes decaying by electron capture or internal conversion

11:10 - 11:30 Coffee

11:30 - 12:10 D.T. GOODHEAD: Physical basis for biological effects

12:10 - 12:35 J.B. VERBERNE, M.V.M. LAFLEUR, H. LOMAN and A. HUMMEL: Radiation chemistry and biological effects: non-homogeneous kinetics of water radicals with biologically active DNA.

12:35 - 13:00 P.D. HOLT: Interpretation of the variation of bacterial sensitivity with radiation quality at high LET using a two-ionization target theory

13:00 - 14:00 Lunch

SESSION II APPLICATIONS AND BEAM PRODUCTION

Chairman: H.G. PARETZKE

14:00 - 14:40 G. DIETZE: Problems in determination of relevant nuclear data used for neutron radiotherapy

14:40 - 15:20 J.J. BROERSE and J. ZOETELIEF: Practical aspects of nuclear particle dosimetry

- 15:20 - 15:40 Coffee
- 15:40 - 16:30 D.K. BEWLEY: Neutron energy spectra and their implications
- 16:20 - 17:00 B.J. MIJNHEER: Protocols for the determination of absorbed dose in a patient irradiated by beams of nuclear particles
- 17:00 - 17:40 M.A. CHAUDHRI: Cyclotron production of fast neutrons for therapy
- 17:40 - 18:30 Cocktail party offered by the IAEA at the Radiobiological Institute TNO

Tuesday, 17 September

SESSION III NEUTRON INTERACTIONS

Chairman: D.K. BEWLEY

- 09:20 - 10:00 W.G. CROSS: Nuclear data for neutron radiotherapy and related radiobiology
- 10:00 - 10:40 J.J. COYNE: Secondary charged particle spectra and kerma calculations
- 10:40 - 11:20 D.J. BRENNER: Cross sections for neutron interactions including kerma values
- 11:20 - 11:40 Coffee
- 11:40 - 12:20 G. BURGER and M. MAKAREWICZ: Average energy to produce on ion pair in gases and related quantities of relevance in neutron dosimetry
- 12:20 - 13:00 K. MORSTIN and A. DYDEJCZYK and J. BOOZ: High-energy neutron interactions with tissue and tissue-equivalent materials

SESSION IV PION INTERACTIONS

Chairman: W.G. CROSS

- 14:00 - 14:40 H.G. MENZEL: Fast neutron and pion interaction data from low pressure proportional counter measurements
- 14:40 - 15:20 H. BLATTMANN: Type and energy spectra of secondaries from interactions of pions and its relevance to radiotherapy
- 15:20 - 15:40 Coffee
- 15:40 - 16:20 J.N. BRADBURY: Pion production cross-sections and associated parameters

16:20 - 17:00 J.R.H. SMITH, K.R. SMITH and D.F. JACKSON:
Measurements of negative pion capture in organic
materials

Wednesday, 18 September

SESSION V CHARGED PARTICLE INTERACTIONS

Chairman: J.N. BRADBURY

09:20 - 10:00 M.J. BERGER: Range and energy loss of electrons
10:00 - 10:40 T. INADA: Data requirements in the present and future
proton radiotherapy
10:40 - 11:20 M. INOKUTI: Cross sections for inelastic collisions of
fast charged particles with atoms and molecules
11:20 - 11:40 Coffee
11:40 - 12:20 T. TAKAHASHI: Data requirements in heavy ion
radiotherapy
12:20 - 13:00 M.N. VARMA and J.W. BAUM: Stopping power for heavy
ions in gases
13:00 - 14:00 Lunch

SESSION VI CHARGED PARTICLE TRACK STRUCTURE

Chairman: T. INADA

14:00 - 14:40 R. KATZ: Track structure and dose: alternative
conceptual bases for nuclear therapy
14:40 - 15:20 H.G. PARETZKE: Parameters characterizing charged
particle track structures
15:20 - 15:40 Coffee
15:40 - 16:20 A. ITO: Calculation of the double strand breaks of DNA
for low LET radiations based on track structure
analysis
16:20 - 17:00 Formation of working groups

Thursday, 19 September

SESSION VII DISCUSSION ON FUTURE NEEDS FOR ATOMIC AND NUCLEAR DATA

Working Group I Beam production and field description

Group leaders: D.K. BEWLEY
J. BRADBURY

Working Group II Dosimetry

**Group leaders: W.G. CROSS
H.G. MENZEL**

Working Group III Interpretation and optimization of biological effect

**Group leaders: M. INOKUTI
H.G. PARETZKE**

Concert by Leni Kuperus, soprano, Jean Savelkoul, flute and Roel Kok, harpsichord at the Stadsherberg 'De Mol', Delft

Dinner offered by the Radiobiological Institute at the Stadsherberg 'De Mol', Delft

Friday, 20 September

SESSION VIII FORMULATION OF RECOMMENDATIONS

Chairman: J.J. BROERSE

09:20 - 11:00	Presentation by leaders of working groups
11:00 - 11:20	Coffee
11:20 - 13:00	Formulation of recommendations
13:00 - 14:00	Lunch
14:00 - 16:00	Formulation of recommendations

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