INDC (NDS)-0484
Distr. G, NM

IAEA
International Atomic Energy Agency

INDC International Nuclear Data Committee

Phase-Space Database for External Beam Radiotherapy

Summary Report of a Consultants' Meeting

organized by

Nuclear Data Section,
Division of Physical and Chemical Sciences
Dosimetry and Medical Radiation Physics Section,
Division of Human Health

IAEA Headquarters
Vienna, Austria

12 – 14 December 2005

Prepared by

R. Capote, IAEA Nuclear Data Section, Vienna, Austria
R. Jeraj, University of Wisconsin, USA
C.-M. Ma, Fox Chase Cancer Center, USA
D.W.O. Rogers, Carleton University, Canada
F. Sánchez-Doblado, University of Seville, Spain
J. Sempau, Universitat Politècnica de Catalunya, Spain
J. Seuntjens, McGill University, Canada
J. V. Siebers, Virginia Commonwealth University, USA

IAEA Headquarters, Vienna, Austria
January 2006

IAEA Nuclear Data Section, Wagramer Strasse 5, A-1400 Vienna, Austria

Selected INDC documents may be downloaded in electronic form from http://www-nds.iaea.org/indc_sel.html or sent as an e-mail attachment. Requests for hardcopy or e-mail transmittal should be directed to services@iaeand.iaea.org or to:

Nuclear Data Section
International Atomic Energy Agency
PO Box 100
Wagramer Strasse 5
A-1400 Vienna
Austria

Produced by the IAEA in Austria
January 2006

INDC(NDS)-0484
Distr. G, NM

Phase-Space Database for External Beam Radiotherapy

Summary Report of a Consultants' Meeting

organized by

Nuclear Data Section,
Division of Physical and Chemical Sciences
Dosimetry and Medical Radiation Physics Section,
Division of Human Health

IAEA Headquarters
Vienna, Austria
12 – 14 December 2005

Prepared by

R. Capote, IAEA Nuclear Data Section, Vienna, Austria
R. Jeraj, University of Wisconsin, USA
C.-M. Ma, Fox Chase Cancer Center, USA
D.W.O. Rogers, Carleton University, Canada
F. Sánchez-Doblado, University of Seville, Spain
J. Sempau, Universitat Politècnica de Catalunya, Spain
J. Seuntjens, McGill University, Canada
J. V. Siebers, Virginia Commonwealth University, USA

Abstract

A summary is given of a Consultants' Meeting assembled to discuss and recommend actions and activities to prepare a *Phase-space Database for External Beam Radiotherapy*. The new database should serve to disseminate phase-space data of those accelerators and ^{60}Co units used in radiotherapy through the compilation of existing data that have been properly validated. Both the technical discussions and the resulting work plan are described, along with the detailed recommendations for implementation. The meeting was jointly organized by NAPC-Nuclear Data Section and NAHU-Dosimetry and Medical Radiation Physics Section.

January 2006

TABLE OF CONTENTS

1. Introduction

Clinical accelerators are widely used in hospitals for the treatment of patients, either to produce electron beams or bremsstrahlung-generated photons. Considerable work is devoted to the physical and clinical dosimetry required for the quality assurance of radiotherapy treatments, from beam characterization to patient treatment delivery. The Monte-Carlo (MC) method has become a widely accepted tool in recent years for the computer simulation of the clinical components of linear accelerators, notably beam generation and collimation, and for the interaction of radiation beams with patients and dosimetric materials. Advanced simulation algorithms and sophisticated computer codes based on the most recent set of cross-section data have become tools for radiotherapy treatment planning of patients at research Centres. Extremely accurate simulations of detector response to accelerator-produced beams are being conducted today for dosimetric purposes.

The accuracy of the calculations depends on the accuracy with which the radiation source is known, and this refers to the detailed description of the energy, direction, position and type of all primary and secondary particles emerging from the clinical accelerator. This description is known as the phase-space (phsp) data of the accelerator. In order to generate such data, very detailed information must be obtained from accelerator manufacturers, sometimes at the level of blueprints. This poses a *de facto* severe limitation on who can have access to phsp data to develop or implement new radiotherapy techniques. Furthermore, the simulation of phsp requires extensive Monte-Carlo expertise for execution and verification.

The present project is designed to establish a public database of phsp data for clinical accelerators and ^{60}Co units used for radiotherapy applications. Such a database will avoid the repetition of lengthy Monte-Carlo calculations performed already by others, will provide a harmonized set of data common to different applications, and will give scientists access to phsp data. The data will be freely available to medical physicists and dosimetry research teams in Member States.

2. Objective and Charge

The objective of the IAEA was to build and to disseminate a phase-space database for accelerators and ^{60}Co units used in radiotherapy through the compilation of existing data that have been properly validated. The consultancy group was asked to provide recommendations on how to achieve this objective.

3. Scope

The primary purpose of the Consultants' Meeting was to provide recommendations to the IAEA with regards to the creation, storage and distribution of phase-spaces for external beam radiation therapy sources. Users targeted by this effort include medical physicists, other researchers, Monte-Carlo users and developers, and accelerator and treatment planning system manufacturers. The areas of application embrace radiation physics and dosimetry (radiation detector dosimetry, treatment planning system algorithm verification, development of parameterized beam models, etc). Imaging for radiation therapy is included in this effort to the extent that imaging devices make use of the radiation treatment beam such as portal imaging devices. The energy and particle types are defined as unlimited (photons, electrons, protons, carbon ions, neutrons, etc) ranging from 1 keV to several GeV. However, the focus of the project has been on photon and electron beams, and brachytherapy sources are not included at this stage of the proposed work programme.

4. Definition and Format of Phase-space Data

A phsp is defined as a collection of representative pseudo-particles emerging from a radiation therapy treatment source along with their properties that include energy, particle type, position, direction, progeny and statistical weight. Every pseudo-particle in the phsp should be scored in such a way that it is recorded only once during the course of passage through the scoring surface (i.e., no further recording of the same particle or descendents). A phsp can take the form of a computer file containing the detailed description of the phsp particles, i.e., phsp variables as generated via a Monte-Carlo simulation of the treatment source, or the form of a computer code (event generator) which simulates the treatment source using either a full Monte-Carlo simulation or beam model of the radiation therapy source. For the purposes of consistency, a standardized format is recommended for the phsp variables. This format consists of a header file that specifies the format of the data or event generator code, including the byte order of the stored information. Information that defines the phsp variables stored in a phsp file or returned by a phsp event generator is listed in Table 1.

Table 1. Information to be returned from a phsp.

Variable	Meaning	Type of variable returned
`X`	Position in X direction in cm	Real*4
`Y`	Position in Y direction in cm	Real*4
`Z`	Position in Z direction in cm	Real*4
`U`	Direction cosine along X	Real*4
`V`	Direction cosine along Y	Real*4
`E`	Kinetic energy in MeV	Real*4
`Statistical_Weight`	Particle statistical weight	Real*4
`Particle_type`	Type of the particle	Integer*2
`Sign_of_W`	Sign of W (direction cosine in Z)	Logical*1
`Is_new_history`	Signifies if particle belongs to new history	Logical*1
`Integer_extra`	Extra storage space for variables (e.g., EGS LATCH, incremental history number, PENELOPE ILB, etc.)	n*(Integer*4) ($n \geq 0$)
`Float_extra`	Extra storage space for variables (e.g., EGS ZLAST)	m*(Real*4) ($m \geq 0$)

Note that for each phase space variable saved, the header will specify if the data are stored in the phsp file, or if a constant value is to be used instead. For example, phsp data stored at a common z-plane would not need to store the z component in the phsp file; rather, the z-component would be specified in the header instead. Binary phsp records are to be stored without record delimiters.

4.1. Content of header

Each header file is a separate ASCII file consisting of mandatory and optional information elements interspersed with comments, as required. The header format suggested below forms the basis for initial phsp submissions by members of the consultancy group. Following the testing of this process by the Agency and selected experts, this format will be fixed and formalized.

1. Phsp format
   a. file type: data file or event generator,
   b. byte order of the data storage,
   c. for each variable, specify variable or constant and how it is stored,
   d. total record length,
   e. check sum for integrity of binary file.

2. Mandatory description of the phsp
   a. number of original histories and number of particles of each type for phsp file, OR
   a'. name of input file for event generator,
   b. description of coordinate system, origin.

3. Mandatory additional information
   a. Agency ID,
   b. title,
   c. machine type,
   d. Monte-Carlo code and code version used for phsp generation,
   e. energy cut-off parameters,
   f. transport parameters.

4. Optional description of the phsp
   a. nominal beam name,
   b. field size,
   c. nominal source surface distance,
   d. variance reduction techniques applied,
   e. initial source description (for example, electron beam radius, spatial and energy distribution, phsp, etc.),
   f. documentation section:
      i. could contain an input file, cross-section dataset information, and sequence and type of CMs for the simulation,
      ii. authorship and reference (http link to journal or internal report) assumed to be the preferred citation,
      iii. link to validation documentation.

5. Optional statistical information on phsp
   a. for each particle type, mean energy, min and max energy,
   b. min and max radius, min and max coordinats X, Y, Z,
   c. supplementary information on phsp.

4.2. Number of particles per unit area

The number of particles per unit area should be included in the information provided by the submitter. A general rule is to use 10000 primary particles per unit area of interest to obtain an approximate 1% statistical uncertainty. The minimal number of particles per unit area for radiation therapy fields should be around 2500 particles/mm^2 at the isocentre plane. The actual required number of particles per unit area requires additional investigation with respect to issues such as latent variance of the phsp.

5. Phase-space Submission

The phsp submitter should comply with the new IAEA format because the IAEA has committed to provision of subroutines to read and write IAEA-format files. These subroutines can be called to extract particles from the phsp or write particles back to a phsp. They also form the basis of a reader program to examine particle coordinates in ASCII and generate optional statistical information that can be stored in the file header. Consultants agree to provide existing conversion routines for commonly available simulation packages (MCNP, EGS, PENELOPE, etc).. The IAEA format (and corresponding read/write subroutines) should be disseminated to MC communities (EGS, PENELOPE, MCNP, GEANT, FLUKA, etc) to encourage compliance to the format.

If an event generator is specified in the header, the attached event generator code must provide particle records consistent with the information agreed upon.

5.1. Validation and documentation criteria

A committee consisting of recognized experts in the area of accelerator Monte-Carlo simulations should be appointed and coordinated by the IAEA. This body should assess submitted data and rank the quality of the submission using well specified criteria.

Essential validation and documentation criteria should consist of the following:

5.1.1. Direct measurements

Any possible direct measurement of source or phsp parameters such as spectra by means of Compton or other spectrometers, source size measurements using spot size cameras, etc.

5.1.2. Indirect measurements

Most commonly provided method of phsp validation that can consist of comparison of the calculated values with the following:

a) in-air measurements;
b) in-phantom measurements at multiple depths and for multiple SSDs
  i) water phantom,
  ii) alternate phantom materials,
  iii) heterogeneous phantoms;

c) measurement in specialized configurations (e.g., narrow beams, use of a Pb beam modifier, etc.);
d) measurements using different detectors - extent to which individual characteristics of detector response are taken into account in the comparison and the level of agreement of these detectors will determine the value of the validation.

A broad range of experimental data obtained by varying conditions for a fixed basic geometry can be provided to validate a given phsp. The more experimental or other data that can be provided to support the validation, the greater merit can be assigned to the phsp. An ideal comparison is one in which the detector has been included in the validation simulations. Realistically, this approach is not always possible and, under such circumstances, any approximation needs to be documented. For example, beyond the depth of maximum dose in broad photon beams, variations of ratios of average restricted stopping powers as a function of depth are normally ignored, and normalized raw ionization measurements can be used directly in the comparison as long as the effective point of measurement is used to specify the depth of measurement.

5.1.3. Consistency checks

Submitters should ensure that their files are in IAEA format.

5.1.4. Documentation of inputs

Submitters should provide all relevant documentation of the input parameters used in their calculations by populating as many fields as possible in the optional section of the header. Ideally, every submitter should provide the input files of their Monte-Carlo code and a complete specification of the version used.

5.1.5. Previous code validation

Submitters may be requested to provide information on validation work undertaken on the codes used to generate the phsp.

5.2. IAEA phsp storage policy

The IAEA should generally accept submissions of families of phsps of which at least a representative phsp has been experimentally validated. Members of the family could differ from the validated representative phsp by varying well-documented input parameters to the Monte-Carlo model for the same fixed portion of the geometry. These input parameters (primary energy, primary electron beam radius, etc.) are typically varied in an optimization process to reconcile Monte-Carlo calculated and measured dosimetric quantities (percent depth dose, profiles, etc) in the irradiation set-up and under the experimental conditions of the submitter. If the varied input parameter corresponds to an experimentally verifiable situation (e.g., field size is varied), the experimental data supporting the validity of the phsp data should also be submitted. The range of applicability of the phsp data needs to be documented in all cases.

When different datasets for the same nominal beam are submitted, the Agency should reserve the right to include only the dataset considered to be the “best available” at that time.

5.3. Submission mechanism and review process

Prior to acceptance into the database, the Agency will perform a format consistency and compliance check on each phase-space submission. When the format is found to be compliant, an *ad-hoc* review panel of three committee members will be established to review the submission. The Agency and/or the review panel may communicate with the submitter to clarify the submission with respect to the requirements.

Each submitter should obtain the necessary permissions to distribute such information when required by confidentiality agreements. The review panel should send in their assessment of each submission that will determine whether a submission is satisfactory or not. The Agency should coordinate the approval process by the appointed panel. If the review panel does not reach an agreement on acceptance, then the IAEA should consult other committee members.

A password protected information exchange system will be located under the IAEA Nuclear Data Section webpage (http://www-nds.iaea.org/reviewphsp/). When the review process has been completed, a summary statement of the review will be incorporated into the header document that may also include an assessment of the ranking of the phsp quality including any statement of caution, emphasizing limitations, etc. A disclaimer should be created which waives responsibilities of use and, in particular, includes a statement not to use Agency-provided phsp information for patient treatment or for purposes other than education and research.

The header file should contain a preferred citation as suggested by the authors, plus a reference to the database along the lines:
"Available online at http://www-nds.iaea.org/phsp/, IAEA, Vienna",
and a unique index defined by the Agency.

5.4. Initial submission of phsp data and testing of the submission process

An initial set of phsp data will consist of fields applicable to reference dosimetry conditions for ^{60}Co, along with high-energy photon and electron beams for existing major accelerator manufacturers.

6. Recommendations

The Agency should undertake the following:

1. administer and maintain the phase-space database for external beam radiation therapy;
2. define a database format capable of holding the phase space and header information as specified in this document,
3. provide reader and writer computer codes to process the agreed information,
4. work with selected research groups to administer the submission of a number of initial data sets for major machine types,
5. receive phsp data for review and possible inclusion in the database,
6. review each submission for compliance with the defined format,
7. create a committee consisting of recognized experts to review database submissions,
8. make the database accessible through the WWW and mass storage media such as DVD,

9. review database submission, maintenance, selection criteria and distribution procedures, and assess their merit and value within two years of implementation.

One further recommendation is that accelerator manufacturers should be approached and asked to release the input files used to generate database entries.

7. Timeframe of Implementation

January - February 2006:	Web-page design; phsp reader/writer subroutine development.
March - April 2006:	Distribution of the reader/writer to selected experts for testing and implementation; Password protected web-page becomes operational and will be ready for submissions.
May - August 2006:	Initial submissions received, reviewed and tested.
September 2006:	Web-page established, and will be ready for submissions.
December 2006:	First review of the start-up process.
November - December 2007:	Review of the first 18 months of operation.

Appendix 1

LIST OF PARTICIPANTS

CANADA
David W.O. Rogers
Physics Department
Carleton University
1125 Colonel By Dr
Ottawa, ON K1S 5B6
Tel. +613 520-2600 4374
Fax +613 520-4061
E-mail: drogers@physics.carleton.ca

UNITED STATES OF AMERICA
Charlie Ma
Radiation Physics
Dept. of Radiation Oncology
Fox Chase Cancer Centre
333 Cottman Av
Philadelphia, PA 19111
Tel. +215 728-2996
Fax. +215 728-4789
E-mail: charlie.ma@fccc.edu

SPAIN
Francisco Sánchez-Doblado
Dpto. Fisiología Médica y Biofísica
Facultad de Medicina
Universidad de Sevilla
Avda. Sánchez Pizjuán 4
E-41009 Sevilla
Tel. +34-954-556102
Fax +34-954-556102
E-mail: paco@us.es

UNITED STATES OF AMERICA
Jeffrey V. Siebers
Department of Radiation Oncology
Virginia Commonwealth University
401 College Street
PO Box 980058
Richmond, VA 23298
Tel. +804 628-7771
Fax +804 827-1670
E-mail: jsiebers@vcu.edu

UNITED STATES OF AMERICA
Robert Jeraj
Department of Medical Physics
University of Wisconsin – Madison
1530 MSC, 1300 University Ave
Madison WI 53706
Tel. +1 608-263-8619
Fax +1 608-262-2413
E-mail: rjeraj@wisc.edu

CANADA
Jan Seuntjens
McGill University,
Medical Physics Unit\Montreal General Hospital
1650 Cedar Avenue
Montreal,
H3G 1A4 Quebec
Tel. +1 514 934 1934
Fax +1 514 934 8229
E-mail: jseuntjens@medphys.mcgill.ca

SPAIN
Josep Sempau
Institut de Tècniques Energètiques
Universitat Politècnica de Catalunya
Diagonal 647
E-08028 Barcelona
Tel. +34 93 401 6074
Fax +34 93 401 7149
E-mail: josep.sempau@upc.es

IAEA

Pedro Andreo
Division of Human Health
Department of Nuclear Sciences and Applications
Wagramer Strasse 5
A-1400 Wien
Tel. +43 1 2600 21650
Fax +43 1 26007
E-mail: P.Andreo@iaea.org

IAEA

Roberto Capote Noy
Nuclear Data Section
Division of Physical and Chemical Sciences
Department of Nuclear Sciences and Applications
Wagramer Strasse 5
A-1400 Wien
Tel. +43 1 2600 21713
Fax +43 1 26007
E-mail: R.CapoteNoy@iaea.org

Ken Shortt
Division of Human Health
Department of Nuclear Sciences and Applications
Wagramer Strasse 5
A-1400 Wien
Tel. +43 1 2600 21664
Fax +43 1 26007
E-mail: K.Shortt@iaea.org

Alan Nichols
Nuclear Data Section
Division of Physical and Chemical Sciences
Department of Nuclear Sciences and Applications
Wagramer Strasse 5
A-1400 Wien
Tel. +43 1 2600 21709
Fax +43 1 26007
E-mail: A.Nichols@iaea.org

Stanislav Vatnitsky
Division of Human Health
Department of Nuclear Sciences and Applications
Wagramer Strasse 5
A-1400 Wien
Tel. +43 1 2600 21660
Fax +43 1 26007
E-mail: S.Vatnitsky@iaea.org

Appendix 2

Consultants' Meeting

'Phase space database for external beam radiotherapy

IAEA Headquarters, Vienna, Austria

12-14 December 2005

Meeting Room F0579

Agenda

Monday 12 December

08:00 - 09:00	Registration (at Gate 1, IAEA Headquarters)
09:00 - 09:30	Welcoming address by IAEA representatives from Division of Human Health and Division of Physical and Chemical Sciences Discussion and adoption of the Agenda
09:30 - 10:15	**Coffee break** (Administrative and Financial Matters)
10:15 - 10:30	Presentation of the project: Roberto Capote
10:30 - 12:00	Discussion
12:00 - 14:00	**Lunch break**
14:00 - 18:00	Discussion

Tuesday, 13 December

09:00 - 10:30	Discussion
10:30 - 10:45	**Coffee break**
10:45 - 12:00	Discussion
12:00 - 14:00	**Lunch break**
14:00 - 18:00	Discussion

Wednesday, 14 December

09:00 - 10:30	Review of the recommendations, draft of the meeting report
10:30 - 10:45	**Coffee break**
10:45 - 12:00	Draft of the meeting report (continue)
12:00 - 14:00	**Lunch break**
14:00 - 16:00	Review meeting report. Conclusions and closing of the meeting

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.org
fax: (43-1) 26007
cable: INATOM VIENNA
telex: 1-12645
telephone: (43-1) 2600-21710