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Summary Report

First Research Coordination Meeting on

Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

IAEA Headquarters
Vienna, Austria

3 – 7 December 2012

Prepared by

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Abstract

A summary is given of the first IAEA research coordination meeting on "Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production". Participants re-assessed and reviewed the requirements for both cross-section and decay data, based on the earlier findings of three IAEA consultants' meetings (High-precision beta-intensity measurements and evaluations for specific PET radioisotopes, INDC(NDS)-0535, December 2008; Improvements in charged-particle monitor reactions and nuclear data for medical isotope production, INDC(NDS)-0591, September 2011; Intermediate-term nuclear data needs for medical applications: cross sections and decay data, INDC(NDS)-0596, September 2011). While significant emphasis was placed on the needs defined in IAEA report INDC(NDS)-0591, a limited number of relevant items and issues were also considered from the other two technical meetings.

Recommendations focused on cross-section studies for a reasonably wide range of targets and projectiles, along with decay data measurements and evaluations for specific radionuclides. Individual presentations and discussions are described in this report, along with listings of the agreed work packages to be undertaken by the participants of the coordinated research project.

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1. Introduction

Many useful or potentially useful radionuclides have been identified for various life-saving diagnostic and therapeutic applications in nuclear medicine. The production routes and decay properties of all such radionuclides need to be well defined, but deficiencies exist, especially with respect to the optimum production of specific radionuclides, minimization/elimination of impurities, and adequate quantification of various decay parameters (e.g., half-life, and alpha-particle, electron, positron, gamma-ray and X-ray emission probabilities for important dose calculations).

Cyclotrons and accelerators are being used in an increasing number of countries to produce radionuclides for both diagnostic and therapeutic purposes, along with reactors employed to produce specific activation and fission products. Such nuclear data needs were initially addressed by a Coordinated Research Project (CRP) on "Charged Particle Cross-Section Database for Medical Radioisotope Production: Diagnostic Radioisotopes and Monitor Reactions" that concluded in 2001 with the publication of IAEA-TECDOC-1211[1]. Equivalent requirements for the production of therapeutic radionuclides were addressed through a further CRP on "Nuclear Data for the Production of Therapeutic Radionuclides" which started in 2003 and was completed in 2007. This second CRP produced a much needed database and handbook[2] covering reactions used for medically important therapeutic radionuclides. The database containing all of the recommended data from both CRPs is available on:
http://www-nds.iaea.org/medportal/

The improved quality of the nuclear data that was generated during those CRPs made radionuclide production much more efficient, and also enhanced nuclide quality through improved purity.

Following on from the above studies, a consultants' meeting was held on "High-Precision Beta-Intensity Measurements and Evaluations for Specific PET Radioisotopes" from 3 to 5 September 2008 at IAEA Headquarters, Vienna, Austria. Participants assessed and reviewed the decay data for about 50 positron-emitting radionuclides, and recommended a series of measurements and evaluations to improve the known decay characteristics of these existing or potential PET nuclides[3]. A further consultants' meeting was held on "Improvements in Charged-Particle Monitor Reactions and Nuclear Data for Medical Isotope Production" from 21 to 24 June 2011, at the same venue[4]. Specific recommendations from both of these consultants' meetings were brought together in June 2011 to formulate and agree the scope, work programme and deliverables of a proposed Coordinated Research Project designed to

[1] IAEA-TECDOC-1211, "Charged Particle Cross-Section Database for Medical Radioisotope Production: Diagnostic Radioisotopes and Monitor Reactions", IAEA Technical Report, Vienna, May 2001. Available online: http://www-nds.iaea.org/publications/tecdocs/iaea-tecdoc-1211.pdf

[2] "Nuclear Data for the Production of Therapeutic Radionuclides", E. Běták, A.D. Caldeira, R. Capote, B.V. Carlson, H.D. Choi, F.B. Guimarães, A.G. Ignatyuk, S.K. Kim, B. Kiraly, S.F. Kovalev, E. Menapace, A.L. Nichols, M. Nortier, P. Pompeia, S.M. Qaim, B. Scholten, Yu.N. Shubin, J.-Ch. Sublet and F. Tárkányi, IAEA Technical Reports Series No. 473, 2011, Editors: S.M. Qaim, F. Tárkányi and R. Capote, International Atomic Energy Agency, Vienna, Austria, ISBN 978-92-0-115010-3.

[3] R. Capote and A.L. Nichols, Consultants' Meeting on "High-precision beta-intensity measurements and evaluations for specific PET radioisotopes", 3-5 September 2008, IAEA report INDC(NDS)-0535, December 2008, IAEA, Vienna, Austria. Available online at http://www-nds.iaea.org/publications/indc/indc-nds-0535.pdf

[4] R. Capote and F.M. Nortier, Consultants' Meeting on "Improvements in charged-particle monitor reactions and nuclear data for medical isotope production", 21-24 June 2011, IAEA report INDC(NDS)-0591, September 2011, IAEA, Vienna, Austria. Available online at http://www-nds.iaea.org/publications/indc/indc-nds-0591.pdf

focus on improvements in charged-particle monitor reactions and nuclear data for medical radionuclides (see IAEA report INDC(NDS)-0591, August 2011[4]).

Continued developments in medical imaging and therapy utilizing novel diagnostic and therapeutic techniques and the production of new radionuclides necessitated a detailed intermediate-term review in 2011. Thus, a technical meeting was held on "Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data" from 22 to 26 August 2011, at IAEA Headquarters, Vienna, Austria[5]. Detailed recommendations were made in IAEA report INDC(NDS)-0596, including the need to further expand the database over a timescale defined as stretching between approximately 5 and 15 years (up to 2025).

M. Venkatesh (Director, NAPC) welcomed the participants. She emphasized the significance of their role in measuring, evaluating and recommending important nuclear data for the production and characterisation of radionuclides to be used in existing and future medical applications. The primary objective of the meeting should be to identify, agree and undertake a series of CRP-based work programmes to improve production methods, radionuclidic purity, and the quantification of various important decay characteristics. Eleven CRP participants (F.T. Tárkányi, M.-M. Bé, B.V. Carlson, M. Hussain, A.V. Ignatyuk, G. Kim, O. Lebeda, A. Luca, T. Nagai, M. Nortier and I. Spahn) and two consultants (F.G. Kondev and A.L. Nichols) attended, while the IAEA was represented by R. Capote (Scientific Secretary, Nuclear Data Section). F.T. Tárkányi (Institute of Nuclear Research, Hugarian Academy of Sciences (excitation functions)) and A.L. Nichols (University of Surrey, Guildford, UK (decay data)) were elected co-Chairman of the meeting, and A.L. Nichols also served as rapporteur. The approved Agenda is attached (Appendix 1), as well as a list of all participants and their affiliations (Appendix 2). Although H. Naik was unable to attend the first research coordination meeting, a short presentation was given on his behalf by R. Capote.

2. Presentations

Presentations by the participants and consultants are available on IAEA-NDS web page
http://www-nds.iaea.org/CRP-CP-monitor/1RCM

2.1. Intermediate- and Longer-term Nuclear Data Requirements for Medical Applications, A.L. Nichols (University of Surrey, UK)

One important aspect of IAEA work is to assist all member states in the peaceful application of nuclear science, of which one significant area is disease prevention/control particularly with respect to the adoption of diagnostic/therapeutic radionuclides in nuclear medicine and radiotherapy. Over the course of the previous five years, a number of initiatives have been undertaken under the auspices of the IAEA Nuclear Data Section to ensure that the nuclear data requirements for medical applications are identified and agreed in a timely manner. Experts in the field have attended a series of IAEA technical meetings to debate the detailed needs for improved measurements and/or evaluations of (a) reaction cross sections to improve the optimum production and radionuclidic purity of particular radionuclides, and (b) decay data for their accurate characterisation to assist in their handling and to quantify dose with greater confidence.

[5] A.L. Nichols, S.M. Qaim and R. Capote, Technical Meeting on "Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data", 22-26 August 2011, IAEA report INDC(NDS)-0596, September 2011, IAEA, Vienna, Austria. Available online at http://www-nds.iaea.org/publications/indc/indc-nds-0596.pdf

These IAEA-NDS sponsored discussions considered possible nuclear data requirements up to approximately 2025, and the resulting recommendations are contained within the individual reports listed below:

- consultants' meeting on "High-precision beta-intensity measurements and evaluations for specific PET radioisotopes", 3-5 September 2008, IAEA Headquarters, Vienna, Austria, IAEA report INDC(NDS)-0535, December 2008;
- consultants' meeting on "Improvements in charged-particle monitor reactions and nuclear data for medical isotope production", 21-24 June 2011, IAEA Headquarters, Vienna, Austria, IAEA report INDC(NDS)-0591, September 2011;
- technical meeting on "Intermediate-term nuclear data needs for medical applications: cross sections and decay data", 22-26 August 2011, IAEA Headquarters, Vienna, Austria, IAEA report INDC(NDS)-0596, September 2011.

These three specialist meetings were followed by a more substantial technical meeting at which reviews and advice were given with respect to long-term needs (defined as next 10 to 20 years) and possible NDS technical programmes and data projects: technical meeting on "Long-term needs for nuclear data development", 2-4 November 2011, IAEA Headquarters, Vienna, Austria, IAEA report INDC(NDS)-0601, January 2012.

While CRP participants should place considerably more emphasis on the recommendations of the consultants' meeting on "Improvements in charged-particle monitor reactions and nuclear data for medical isotope production" for obvious reasons, consideration should also be given to related features of the other two specialist meetings held in September 2008 and August 2011. Adopting this approach, requirements for additional and/or improved nuclear data are specified in IAEA report INDC(NDS)-0591, and can be summarised as follows:

- improve and extend excitation functions for monitor reactions producing ^{22,24}Na, ^{46}Sc, ^{56,58}Co, ^{62,63,65}Zn and ^{96}Tc^{m+g};
- extend and recommend excitation functions for the production of diagnostic γ emitters ^{99}Tc^{m} (both the ^{99}Mo and ^{99}Tc^{m+g} production routes), ^{111}In and ^{123}I (including production routes for ^{123}Cs and ^{123}Xe, and ^{121}I impurity);
- update/recommend excitation functions for the direct production of β^+ emitters ^{52}Fe, ^{55}Co, ^{61}Cu, ^{66,68}Ga, ^{72}As, ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m}, ^{110}In^{m} and ^{120}I;
- update/recommend excitation functions for generators of β^+ emitters ^{62}Zn/^{62}Cu, ^{68}Ge/^{68}Ga, ^{72}Se/^{72}As and ^{82}Sr/^{82}Rb;
- recommend excitation functions for therapeutic α emitters ^{225}Ac (and parent ^{225}Ra(β^-)^{225}Ac), ^{230}U and ^{227}Th/^{223}Ra;
- recommend excitation functions for electron and X-ray emitter ^{131}Cs (and ^{131}Ba parent);
- specific decay-data measurements and comprehensive decay-scheme evaluations for ^{52}Fe, ^{61,64}Cu, ^{62,63}Zn, ^{66}Ga, ^{72}As, ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m}, ^{103}Pd, ^{120}I, and ^{230}U decay chain (^{230}U(α)^{226}Th(α)^{222}Ra(α)^{218}Rn(α)^{214}Po(α)^{210}Pb(β^-)^{210}Bi(β^-)^{210}Po(α)^{206}Pb).

Major aims for attendees at the first IAEA research coordination meeting should be to agree and, if necessary, modify this above extensive list of nuclear data needs as defined originally in June 2011. Known proposals by participants should also be considered in detail, and some extension in the resulting programme of work is envisaged as a consequence of this particular exercise. Possible complementary overlaps between the planned CRP studies and related recommendations to be found in IAEA reports INDC(NDS)-0535 and 0596 can also be expected to impact in some degree upon the resulting work to be undertaken by participants. Such links should be encouraged, although the envisaged emphasis of the existing CRP will remain with the recommendations to be found in IAEA report INDC(NDS)-0591.

Nichols possesses extensive experience in the comprehensive evaluation of decay data, working previously on the development of IAEA decay databases for the establishment and updating of both *X-ray and γ ray decay data standards for detector calibration and other applications* (1986-1990, and 1998-2005), and *Decay data library of the actinides* (1978-1986 and 2005-2012). The equivalent expertise of three willing decay-data evaluators within the existing CRP implies a work load of approximately six or seven radionuclides per specialist, and Nichols proposed specific personal contributions of comprehensive decay-scheme data for ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m}, ^{103}Pd and ^{120}I (**secretary's note**: subsequently modified as shown in Tables 1, 3 and 5 to ^{63}Zn, ^{73}Se, ^{76}Br, ^{89}Zr, ^{94}Tc^{m} and ^{120}I, with a reviewing role for ^{103}Pd (direct DDEP evaluation)).

2.2. Overview of Relevant Activities of the Laboratoire National Henri Becquerel (LNHB), M.-M. Bé (LNHB, CEA Saclay, France)

The duties of the Laboratoire National Henri Becquerel (LNHB) as the national metrology institute (NMI) of France were described. Specific instruments are used to maintain and upgrade the references for activity (Becquerel) and dosimetry (Gray) measurements. Since all methods require sound knowledge of decay scheme data, particular group activities within LNHB are dedicated to such studies. Thus, the DDEP (Decay Data Evaluation Project) was launched by LNHB and co-workers to form an international working group of evaluators to derive well-defined decay scheme data for adoption by all users of ionising radiation. Evaluations undertaken by DDEP members are sent to LNHB for publication. The opportunity was taken in 2004 to publish the results of DDEP evaluations in a *BIPM Monographie* series, under the auspices of the CCRI (Consultative Committee for Ionising Radiation). Six volumes have subsequently been published and a seventh is in preparation, while two dedicated web sites also provide access to the evaluated datasets and are updated regularly: www.nucleide.org and laraweb.free.fr

A DDEP evaluation is based upon a set of rules and methodology which starts with a close examination of all published papers, and finishes with various careful checks of the overall consistency of the proposed decay scheme. Several nuclides of interest for medical applications have already been evaluated in this way: ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{32}P, ^{22}Na, ^{24}Na, ^{60}Co, ^{64}Cu, ^{66}Ga, ^{67}Ga, ^{68}Ge/^{68}Ga, ^{89}Sr, ^{90}Y, ^{99}Tc^{m}, ^{111}In, ^{123}I, ^{125}I, ^{131}I, ^{134}Cs, ^{137}Cs, ^{153}Sm, ^{159}Gd, ^{166}Ho, ^{169}Yb, ^{177}Lu, ^{186}Re, ^{188}Re, ^{192}Ir, ^{201}Tl, ^{203}Pb, ^{211}At/^{211}Po, ^{223}Ra and ^{213}Bi/^{225}Ac (as of 22 November 2012). Some of these evaluations were undertaken in the context of two previous IAEA CRPs (*Update of X- and gamma-ray standards* and *Updated decay data library for actinides*).

All resulting decay data need to be well categorized, i.e. internal conversion sub-shell coefficients, sub-shell capture probabilities, Auger-electron emission probabilities, etc. (example calculation of the Auger-electron energies and emission probabilities emitted in ^{125}I(EC)^{125}Te was shown). A series of comments and suggestions were also made relating to the CRP:

1) need to take into account possible impurities created during production, e.g. ^{201}Tl which is often produced with ^{200}Tl and ^{202}Tl, resulting in difficulties determining the specific activity of ^{201}Tl in solution;
2) useful for those undertaking new decay data measurements to have a list of possible producers of the nuclides of interest;
3) all decay-scheme evaluations should be carried out following the DDEP methodology to ensure consistency and uniformity;

4) as specific CRP outputs, LNHB staff will evaluate the ^{61}Cu decay scheme and, in collaboration with IFIN-HH, Bucharest, the decay schemes of all radionuclides constituting the ^{230}U decay chain.

2.3. Nuclear Data Research Capabilities at the Argonne National Laboratory (ANL), F.G. Kondev (ANL, USA)

Both the ATLAS and APS facilities at ANL was described, including details of several experimental instruments and detector systems that can be used to undertake decay-data measurements along with detailed evaluations for a number of nuclides of interest to the CRP. Specifically, decay-data measurements on ^{66}Ga, ^{86}Y and ^{67}Cu were proposed, along with comprehensive decay-data evaluations for these particular nuclides. An evaluation of the half-life of ^{44}Ti of relevance to the on-going cross-section measurements will also be carried out at ANL.

Experimental results will be published in scientific journals, and all relevant data will be made available to all members of the CRP prior to their publication. Evaluated data in ENSDF format will be communicated to IAEA-NDS for inclusion in an established database within the "Medical Isotopes Portal", which has been identified as a suitable focal point for the assembly of agreed sets of cross-section and decay data for medical isotopes.

2.4. Decay Data Evaluations at the Radionuclide Metrology Laboratory (LMR), A. Luca (National Institute of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Romania)

Previous experience acquired by LMR staff in the field of nuclear decay data measurements and evaluations has included participation in the IAEA coordinated research project on *Updated decay data library for actinides* (2005-2012) and collaboration with Laboratoire National Henri Becquerel (LNHB), CEA Saclay, France. Current involvement of LMR in research projects related to nuclear data was discussed, along with relevant publications. A new TR-19 cyclotron was also installed in 2012 at the Radioisotopes and Radiation Metrology Department of IFIN-HH, to produce radionuclides for radiopharmaceutical research.

Proposed IFIN-HH contributions to the new IAEA CRP will be decay data evaluations for the following radionuclides: ^{52}Fe and radionuclides within the ^{230}U decay chain defined as $^{230}U(\alpha)^{226}Th(\alpha)^{222}Ra(\alpha)^{218}Rn(\alpha)^{214}Po(\alpha)^{210}Pb(\beta^-)^{210}Bi(\beta^-)^{210}Po(\alpha)^{206}Pb$(stable), with the work undertaken in cooperation with French colleagues from LNHB, CEA Saclay. Romanian participants will be A. Luca and M.-R. Ioan (PhD student at LMR, IFIN-HH). Previous evaluations will be reviewed, experimental data will be identified and analyzed (NSR, IAEA, and other databases and libraries etc.), followed by the compilation and evaluation of the decay-data sets, and the analysis and testing of the decay schemes to achieve consistency. The data handling procedures of the Decay Data Evaluation Project (DDEP) will be used as appropriate. All results will be disseminated through open publications and presentations at international conferences/workshops. Problems related to LMR participation in the CRP were discussed, including limited sources of funding, training requirements and lack of man-power, along with the difficulty in obtaining radioactive solutions for activity standardization and nuclear decay data measurements.

2.5. ^{232}*Th + p Cross-section Measurements, M. Nortier (Los Alamos National Laboratory (LANL, USA)*

Facilities at LANL have been re-established for the measurement of charged-particle induced reaction cross sections at beam energies up to 800 MeV. Stacked foil irradiations have been performed with 100-, 200- and 800-MeV proton beams generated by the LANSCE accelerator. Non-destructive γ-counting as well as α-spectroscopy and spectral analysis capabilities within the counting laboratory of the Chemistry Division are used for sample assay and accurate quantification of residual activities. Radiochemical separations are also performed on the advice and guidance of the existing radiochemical expertise within LANL.

Recent measurements have focused on cross sections for high-energy proton accelerator production of ^{225}Ac and ^{223}Ra from thorium targets. While these isotopes are normally used for the generation of the radiotherapeutic ^{213}Bi (natural decay product of ^{225}Ac) and ^{211}Pb (natural decay product of ^{223}Ra), both ^{225}Ac and ^{223}Ra are also considered as suitable for direct use themselves. While ^{225}Ac and ^{223}Ra have shown tremendous potential in the treatment of cancer, their widespread use in radiotherapy has been restricted due to lack of availability. For example, the present worldwide supply of ^{225}Ac comes almost exclusively from two ^{229}Th sources located at ORNL and ITU, and is therefore limited.

The anticipated future growth in demand of ^{225}Ac has recently led to the investigation of a number of alternative production routes including accelerator-induced charged-particle reactions. Recent LANL cross-section measurements for ^{225}Ac, ^{225}Ra, ^{227}Th and ^{223}Ra production at 800 MeV and the measured excitation functions at energies below 200 MeV have been published [1, 2]. Together with existing data, they provide a basis for the evaluation of their excitation functions. Measurements for the production of long-lived ^{227}Ac are still in progress. A comparison of theoretical cross sections obtained using codes such as CEM, Bertini, INCL and ALICE2010 with the LANL measurements as well as with other existing data shows that significant disagreement still exists between theory and experiment in some cases, underlying the need for further nuclear model developments (see Fig. 1).

The re-established facilities and recent measurements at LANL provide the means of assisting the CRP through the evaluation of data for higher-energy charged-particle induced production routes, especially those for alpha emitters. New measurements can also be considered.

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[1] J.W. Weidner, S.G. Mashnik, K.D. John, *et al.*, ^{225}Ac and ^{223}Ra production via 800 MeV proton irradiation of natural thorium targets, Appl. Radiat. Isot. **70** (2012) 2590–2595.

[2] J.W. Weidner, S.G. Mashnik, K.D. John, *et al.*, Proton-induced cross sections relevant to production of ^{225}Ac and ^{223}Ra in natural thorium targets below 200 MeV, Appl. Radiat. Isot. **70** (2012) 2602–2607.

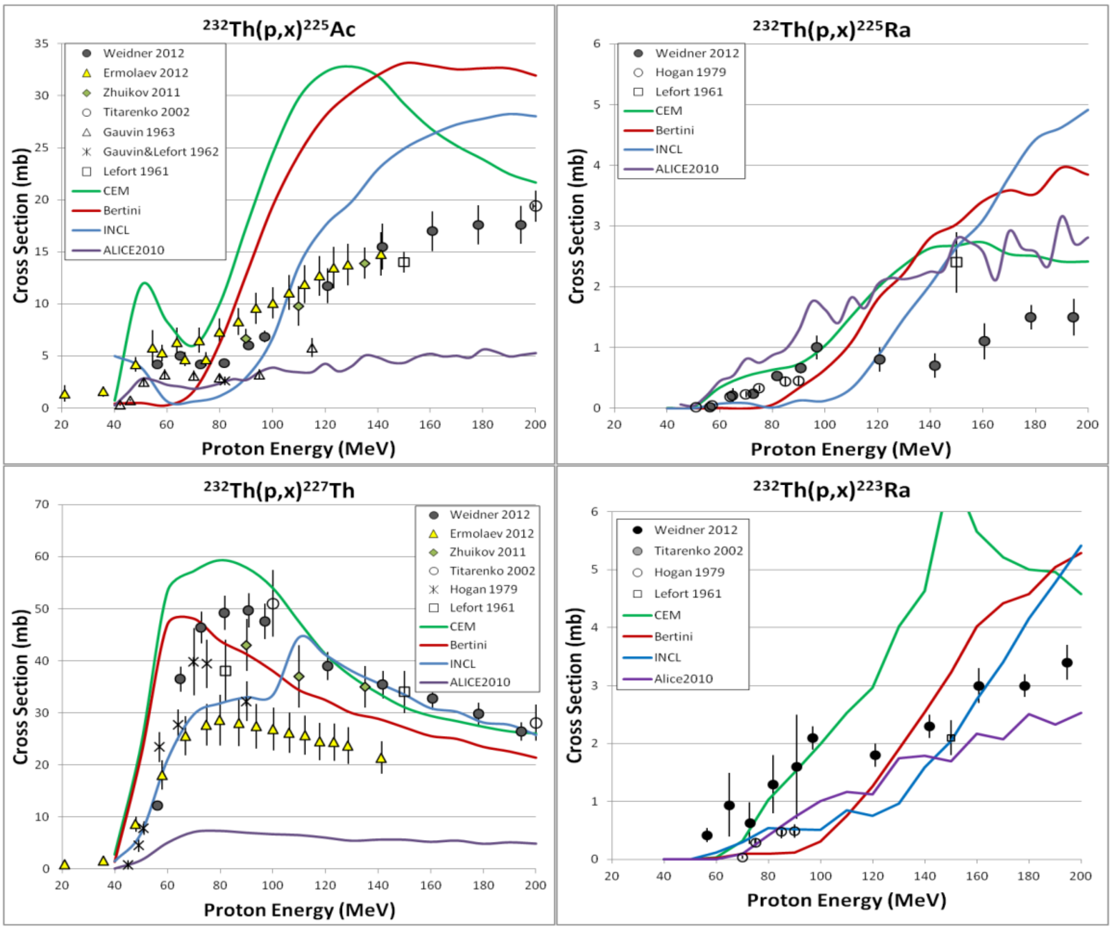

Fig. 1. Comparison of experimental and theoretical cross sections for the production of ^{225}Ac, ^{225}Ra, ^{227}Th and ^{223}Ra from the proton bombardment of ^{232}Th.

2.6. Development of Medical Radionuclides and Nuclear Data Measurements at the Forschungszentrum Jülich, I. Spahn (Institute für Nuklearchemie, Germany)

Studies undertaken by the Radionuclide Development Group of the Nuclear Chemistry Institute (INM-5) in the Department of Neurosciences and Medicine at the Forschungszentrum Jülich focus on the investigation of nuclear reactions for the production of medical radionuclides and the development of radiochemical separation procedures to provide high-purity materials. Radionuclide production in the low-energy region up to 17-MeV proton energy is carried out on Baby Cyclotron BC1710. Additionally, irradiations are also performed in the intermediate energy range up to 45-MeV proton energy and 75-MeV deuteron energy at the injector of COSY (JULIC). Furthermore, commissioning of the new Cyclone 30XP cyclotron at Jülich will enable the investigation of alpha-particle induced nuclear reactions, which could be undertaken in collaboration with other institutes if necessary.

The hot chemistry facilities of the institute are used to perform inorganic and organic wet chemistry operations as well as gas phase studies (e.g. dry distillation, chromatography and electroplating). Both the radiochemical and radionuclidic purity of products and samples as well as the precise determination of specific activities can be achieved and verified by means of the available analytical equipment at INM-5, supplemented by advanced facilities in other research institutions.

Positron-emitting $^{66,68}Ga$, ^{76}Br, ^{45}Ti and $^{44m,g}Sc$ are of increasing relevance to nuclear medical applications. New cross-section measurements and assessments of existing data will be carried out at Jülich in order to produce reliable evaluations of the excitation functions of possible production routes with confidence. Furthermore, the radionuclides will be radiochemically separated in pure carrier-free form to enable X-ray measurements and the determination of positron emission probabilities. High-precision positron emission probabilities may require co-operation with established standards laboratories. The radiochemical expertise of INM-5 staff could also be of assistance in the preparation of thin samples for irradiations related to the investigation of radionuclides studied by other groups working in the CRP.

2.7. Nuclear Data Measurements on U-120M Cyclotron, O. Lebeda (Nuclear Physics Institute (NPI), Czech Republic)

The U-120M cyclotron is a versatile machine for cross-section measurement of charged particle induced reactions (p, d, ^{3}He- and α beam are available; K = 37). Several systematic measurements have been performed:

- excitation functions for $^{231}Pa(p,2n)^{230}U$ and $^{231}Pa(d,3n)^{230}U$ reactions;
- excitation functions for $^{nat}Mo(p,x)$ reactions with respect to ^{95m}Tc, $^{96m+g}Tc$, ^{99m}Tc and ^{99}Mo;
- excitation functions for $^{nat}Mo(d,x)$ reactions with respect to ^{95m}Tc, $^{96m+g}Tc$, ^{99m}Tc and ^{99}Mo;
- excitation functions for $^{nat}Nd(p,x)$ reactions;
- excitation functions for ^{3}He-induced reactions on selected monoisotopic elements;
- assessment of radionuclidic impurities in cyclotron production of ^{99m}Tc via $^{100}Mo(p,2n)$.

The cyclotron is equipped with appropriate beam diagnostic techniques, along with the in-house design and construction of target systems including target holders for the irradiation of stacked foils. Several HPGe detectors are available for gamma spectroscopy that have been calibrated for various sample-detector distances.

Proposed studies within the new CRP on *Nuclear data for charged-particle monitor reactions and medical isotope production* will involve the preparation of the following recommended cross-section data:

- $^{nat}Mo(p,x)^{96m+g}Tc$ monitoring reaction;
- production of ^{99m}Tc and ^{99}Mo via $^{100}Mo(p,2n)^{99m}Tc$, $^{100}Mo(p,x)^{99}Mo$, $^{98}Mo(d,n)^{99m}Tc$, $^{100}Mo(d,3n)^{99m}Tc$, $^{98}Mo(d,p)^{99}Mo$ and $^{100}Mo(d,x)^{99}Mo$ reactions;
- production of ^{61}Cu via $^{61}Ni(p,n)^{61}Cu$ and $^{64}Zn(p,\alpha)^{61}Cu$ reactions;
- production of ^{230}U via $^{231}Pa(p,2n)^{230}U$, $^{231}Pa(d,3n)^{230}U$ and indirect $^{232}Th(p,3n)^{230}Pa \rightarrow ^{230}U$ reactions.

Perform measurements and providing new experimental data for the following reactions:

- cross sections for $^{100}Mo(p,2n)^{99m}Tc$ and $^{100}Mo(p,x)^{99}Mo$ reactions up to 37 MeV, measured on highly-enriched ^{100}Mo;
- cross sections for the $^{64}Zn(p,\alpha)^{61}Cu$ reaction up to 37 MeV, measured on highly-enriched ^{64}Zn;
- cross sections for the $^{75}As(p,3n)^{73}Se$ reaction up to 37 MeV, measured on ^{nat}As;
- cross sections for the $^{89}Y(d,2n)^{89}Zr$ reaction up to 20 MeV, measured on ^{nat}Y;
- cross sections for the $^{nat}Ti(^{3}He,x)^{48}V$ monitoring reaction up to 46 MeV.

2.8. *Expertise and Proposed Studies to be Undertaken for the CRP, F.T. Tárkányi (Institute of Nuclear Research, Hungary)*

The research programme of the ATOMKI Nuclear Reaction Data Group, Institute of Nuclear Research of the Hungarian Academy of Science, consists of measurements, compilations, evaluations and the application of low- and medium-energy charged-particle induced nuclear reaction data. These studies are mainly performed as a series of international projects and collaborations involving cyclotrons with the potential to operate with low-mass charged particle beams up to 100 MeV. One measurement initiative involves the systematic experimental study of activation cross sections of proton- and deuteron-induced reactions for comparison with the results of modern theoretical modeling to establish a more reliable experimental database and prepare a general activation file up to 100-MeV protons and 50-MeV deuterons. Systematic investigations of nuclear data are also underway to determine the production of radioisotopes proposed for use in radiotherapy - resulting experimental data are compared with the results of theoretical calculations undertaken at IPPE and found in existing TENDL libraries.

The ATOMKI Nuclear Reaction Data group has carried out a number of studies of relevance to the current coordinated research project:

- participated in the previous two IAEA CRPs to produce evaluated databases for the production of medical radioisotopes and for well-defined monitor reactions;
- participated in the work of other IAEA CRPs and evaluation projects dedicated to charged particle activation cross-sections (e.g. FENDL-3, TLA, high intensity gas-, liquid and solid targets, and ^{99m}Tc production with accelerators);
- investigated activation cross sections for a significant number of medical radioisotopes and monitor reactions identified with the present CRP (results have been reported in more than 60 publications).

Proposed studies by the ATOMKI group of direct interest and application to the present CRP:

- new measurements to resolve significant disagreements between earlier measurements;
- compilation and critical analyses of experimental cross-section and yield data for monitor reactions, and reactions for production of diagnostic and therapeutic radioisotopes;
- preparation of integral yield data based on evaluated cross sections;
- preparation of a manual describing the measurement and application of charged particle cross sections;
- assist in the preparation of IAEA Technical Report on “Improvements in charged-particle monitor reactions and nuclear data for medical isotope production”.

Previous experience underlines the need to assess and address all existing drawbacks and problems identified with the IAEA nuclear database for medical applications, along with the frequent difficulties noted by compilers and evaluators that arise from a lack of the required experimental detail in published papers. A number of the proposed reactions have already been measured by the ATOMKI group, while other relevant measurements are in progress. ATOMKI staff are also prepared to compile and evaluate CRP-based reactions for which there are no willing volunteers.

2.9. Measurements of Cross Sections of Photon, Neutron and Charged-particle Induced Nuclear Reactions Identified with Medical Radioisotope Production, H. Naik (Bhabha Atomic Research Centre, India)

A three-year plan has been formulated to measure the cross sections and yields of a number of specific radioisotopes of relevance to the IAEA CRP:

a) $^{100}Mo(\gamma,n)^{99}Mo$ and $^{238}U(\gamma,f)^{99}Mo$ reactions
   ^{92}Mo (14.84%), ^{94}Mo (9.25%), ^{95}Mo (15.92%), ^{96}Mo (16.68%), ^{97}Mo (9.35%), ^{98}Mo (24.13%) and ^{100}Mo (9.63%);
b) $^{32}S(n,p)^{32}P$, $^{33}S(n,p)^{33}P$ and $^{47}Ti(n,p)^{47}Sc$ reactions
   ^{32}S (95.02%), ^{33}S (0.75%), ^{34}S (4.2%) and ^{36}S (0.02%);
c) $^{68}Zn(p,n)^{68}Ga$ reaction
   ^{64}Zn (48.6%), ^{66}Zn (27.9%), ^{67}Zn (4.1%), ^{68}Zn (18.8%) and ^{70}Zn (0.6%).

The studies defined above within item (a) will be the focus of experimental work during the first year of the CRP. On-going measurements of the cross sections and yields will be completed for ^{99}Mo production from the $^{100}Mo(\gamma,n)^{99}Mo$ and $^{238}U(\gamma,f)^{99}Mo$ reactions at bremsstrahlung end-point energies of 10 to 25 MeV as generated by the 10-MeV electron linac in India and at higher energies elsewhere (e.g. suitable facilities in Germany, France, Russia and/or Republic of Korea). A preliminary trial study with a small ^{nat}Mo sample has been successfully completed on the 10-MeV electron linac at EBC, Kharghar, India. Productions runs at large sample size and different bremsstrahlung end-point energies will be performed in India and abroad with both ^{nat}Mo and enriched Mo samples.

2.10. Nuclear Data for Medical Radioisotope Production by Means of Accelerator Neutrons, Y. Nagai (Japan Atomic Energy Agency, Japan)

The (n,2n), (n,p), (n,np+d), and (n,α) reactions of a sample nucleus with a medium-weight mass (<100) have sizable cross sections from approximately 50 to 1500 mb over a neutron energy from 10 and 18 MeV. Significant progress has recently been made in accelerator technology to obtain fast neutrons with an intensity of 10^{15} n s^{-1} by means of the $^{nat}C(d,n)$ reaction based on 40-MeV 5-mA deuterons. Neutrons are emitted from the reaction peak at forward angles with respect to the deuteron beam direction, and are characterised by an energy spectrum with a most probable energy of 14 MeV.

On the basis of the features outlined above, JAEA staff will produce the medical radioisotopes of ^{99}Mo, ^{90}Y, ^{64}Cu, and ^{67}Cu from a neutron beam generated by the $^{nat}C(d,n)$ reaction. One of the unique features of the proposal is the capability to produce all of the above-mentioned medical radioisotopes by means of accelerator neutrons. Thus, the $^{nat}C(d,n)$ reaction produces fast neutrons possessing an energy spectrum up to 40 MeV with a most probable energy of 14 MeV that can be used to measure the production yields of ^{99}Mo, ^{90}Y, ^{64}Cu, and ^{67}Cu by the $^{100}Mo(n,2n)^{99}Mo$, $^{90}Zr(n,p)^{90}Y$, $^{64}Zn(n,p)^{64}Cu$, $^{67}Zn(n,p)^{67}Cu$ and $^{68}Zn(n,x)^{67}Cu$ reactions. Cross sections obtained from quasi mono-energetic neutrons generated by the $^{3}H(d,n)^{4}He$ reaction at $E_d \approx 0.35$ MeV will also be measured in order to calibrate the reaction studies of the medical radioisotopes. Measurements will be carried out at Takasaki Ion Accelerators for Advanced Radiation Application (JAEA) and/or Cyclotron Radioisotope Center (Tohoku University) with neutrons from the C(d,n) reaction, and at Fusion Neutronics Source (JAEA) with 14-MeV neutrons from the $^{3}H(d,n)$ reaction.

2.11. *Proposed Evaluation of Monitor and Radioisotope Production Reactions, B.V. Carlson (Instituto Tecnológico de Aeronáutica (ITA), Brazil)*

Extensive data exist for the production of ^{22,24}Na radioisotopes by proton bombardment of ^{27}Al. Data selection followed by cubic spline or Pade fitting is probably the most efficient way to evaluate these reactions. Nevertheless, ITA staff are also interested in modeling these high-energy, multiple-emission cross sections by means of the EMPIRE code.

Novel methods for the production of ^{99}Mo and ^{99m}Tc have been studied as a consequence of the temporary shortage of reactor-produced ^{99}Mo in 2009/2010. A data set exists for the ^{100}Mo(γ,n)^{99}Mo reaction, although the maximum cross section of the order of 150 mb is probably too small for the efficient production of ^{99}Mo in an electron-induced reaction − the thermal-neutron capture cross section of the ^{98}Mo(n,γ)^{99}Mo reaction is of the same order of magnitude at about 200 mb. A fairly consistent set of data exist for the two-neutron removal cross section of the ^{100}Mo(n,2n)^{99}Mo reaction, and furnishes a cross section of the order of 1 b at neutron energies between 9 and 18 MeV, which would require a neutron beam rather than reactor for production. Finally, the proton-induced ^{100}Mo(p,np)^{99}Mo and ^{100}Mo(p,2p)^{99m}Tc reactions are being considered for which several inconsistent data sets exist. The ^{99m}Tc production cross section is approximately a factor of two greater than that of ^{99}Mo, and could provide an alternative means of furnishing this extremely important radioisotope. Evaluation of these cross sections will require a careful examination of the experimental data.

Several not entirely consistent data sets exist for the proton-induced production of α emitters from ^{232}Th. These reactions could probably be most efficiently evaluated on an individual basis through data selection followed by a cubic spline or Pade fit of the data. Furthermore, their simultaneous modeling by means of the EMPIRE code should also be explored.

The DDHMS (Double Differential Hybrid Monte-Carlo Simulation) model provides a suitable method for the calculation of multiple pre-equilibrium emission cross sections in γ or nucleon-induced reactions. ITA staff have extended this approach to produce exclusive cross sections, and have adopted a more appropriate Monte-Carlo sampling procedure to furnish a simplified, semi-classical version of the Feshbach-Kerman-Koonin multistep direct reaction model. Work continues to improve the physical content of the model, of which one aim is to describe the reactions in terms of the DDHMS method within the EMPIRE code.

The CRP-related activities proposed by the ITA group are as follows:

- evaluation of the ^{27}Al(p,x)^{22,24}Na monitor reactions to 200 MeV;
- evaluation of γ-, neutron- and proton-induced reactions on ^{100}Mo for the production of ^{99}Mo and ^{99m}Tc;
- evaluation of the α-emitting ^{225}Ra, ^{225}Ac, ^{227}Th and ^{227}Ac in proton-induced reactions on ^{232}Th up to 200 MeV;
- continue development of the DDHMS module of EMPIRE in order to calculate multiple-emission production cross sections.

2.12. *Measurements of Excitation Functions for Charged-particle Induced Reactions on ^{nat}Fe, ^{nat}Nb, ^{nat}Y and ^{nat}Hf, Guinyun Kim (Kyungpook National University, Republic of Korea)*

The MC 50 cyclotron facility at KIRAMS (Korea Institute of Radiological and Medical Science) will be used to generate the radioisotopes of interest. Excitation functions for the proton-induced reactions of ^{nat}Fe, ^{nat}Nb and ^{nat}Hf, and for the alpha-induced reactions of ^{nat}Fe, ^{nat}Y and ^{nat}W will be measured up to an incident beam energy of 40 MeV by means of the stacked-foil activation technique combined with high resolution γ-ray spectroscopy.

The anticipated outcomes are the production cross sections of the following nuclear processes from their threshold energies to approximately 40 MeV:

- $^{nat}Fe(p,x)^{55,56,57}Co$, ^{51}Cr and $^{52,54}Mn$ reactions;
- $^{nat}Nb(p,x)^{90,93m}Mo$, $^{90,91m,92m,92g}Nb$, ^{88}Zr and ^{88}Y reactions;
- $^{nat}Hf(p,x)^{173,174,175,176,177,178m,180g}Ta$, $^{173,175,179m,180m}Hf$ and $^{172m+g,173,177g}Lu$ reactions;
- $^{nat}Fe(\alpha,x)^{55,56,57,58}Co$, ^{61}Co, ^{56}Mn and $^{56,57}Ni$ reactions;
- $^{nat}Y(\alpha,x)^{90,92m}Nb$, $^{88,89}Zr$ and $^{87m,87g,88,90m,91m}Y$ reactions;
- $^{nat}W(\alpha,x)^{182,182m,183,184,184m,186,188}Re$, ^{187}W and $^{182,183,184}Ta$ reactions.

Emphasis will be placed on specific medical isotopes and their production routes as follows:

- diagnostic γ emitters − $^{nat}Fe(p,x)^{51}Cr$ and $^{nat}W(\alpha,x)^{186,188}Re$;
- β^+ emitters − $^{nat}Fe(p,x)^{55}Co$, $^{93}Nb(p,x)^{90}Nb$, $^{89}Y(\alpha,x)^{90}Nb$ and $^{89}Y(\alpha,x)^{89}Zr$;
- electron and X-ray emitters − $^{176}Hf(\alpha,2n)^{178}W(EC)^{178}Ta$.

Studies of the cross sections for various monitor reactions will also be conducted, i.e. $^{27}Al(\alpha,x)^{22,24}Na$, $^{nat}Cu(p,x)^{58}Co$, and $^{nat}Cu(\alpha,x)^{66,67}Ga$ and ^{65}Zn.

2.13. Evaluation of Production Reactions for Medically Important Positron Emitters, M. Hussain (Government College University, Pakistan)

Research activities of direct relevance to the CRP are based on the proposed evaluation of a range of medically important positron emitters. The production and assessment of excitation functions for various novel positron emitters has been recommended for investigation and quantification. Hence, the research group at Lahore has developed an evaluation methodology for charged-particle induced reactions. The main steps of the adopted procedure are listed below:

1. choice of charged-particle induced reactions (target material, type and energy of charged particle, reaction cross section, competing reactions);
2. compile activation cross-section data from EXFOR and journal publications;
3. scrutinise data for reliability, consistency, etc.;
4. normalize data (extrapolation to 100% enrichment of target material, adjustment of data based on newly evaluated γ-ray intensities (NUDAT), normalization of data to recommended monitor cross sections given in IAEA-TECDOC-1211 or IAEA-NDS web page);
5. compare normalized data with the results of nuclear model calculations (EMPIRE, TALYS, ALICE-IPPE) over a given energy range (model parameters varied within recommended limits (RIPL-2) to obtain a good description of the experimental data);
6. basic consideration − $\sigma_{ev}(E) = \sigma_{model}(E) \times f(E)$ in which $\sigma_{ev}(E)$, $\sigma_{model}(E)$ and $f(E)$ are the evaluated cross section, model calculated cross section and the energy-dependent normalisation factor, respectively;
7. good assumption to approximate $f(E)$ with a third-order polynomial function (ORIGIN code of Origin Lab Corporation used for the fitting procedure);
8. ratio of experimental to calculated data plotted as a function of energy, followed by a polynomial fit (with uncertainties included as the weighting factor) to estimate $f(E)$ in which data beyond 3σ limit are rejected, and the 95% confidence limits obtained for $f(E)$ are transformed back to the cross sections to estimate the uncertainty;
9. evaluation procedure repeated with all model calculations, and the recommended data are generated by averaging the normalized model calculations.

Applying the methodology described above, the following reactions for the production of positron emitters will be evaluated as input to the CRP:

- ^{52}Fe – ^{55}Mn(p,4n)^{52}Fe, ^{nat}Ni(p,x)^{52}Fe and ^{52}Cr(^{3}He,3n)^{52}Fe reactions;
- ^{55}Co – ^{58}Ni(p,α)^{55}Co, ^{54}Fe(d,n)^{55}Co and ^{56}Fe(p,2n)^{55}Co reactions;
- ^{66}Ga – ^{66}Zn(p,n)^{66}Ga, and ^{63}Cu(α,n)^{66}Ga reactions;
- ^{72}As – ^{nat}Ge(p,xn)^{72}As reactions;
- ^{73}Se – ^{75}As(p,3n)^{73}Se and ^{70}Ge(α,n)^{73}Se reactions;
- ^{76}Br – ^{76}Se(p,n)^{76}Br, ^{77}Se(p,2n)^{76}Br and ^{75}As(α,3n)^{76}Br reactions;
- ^{86}Y – ^{86}Sr(p,n), ^{85}Rb(α,3n)^{86}Y and ^{88}Sr(p,3n)^{86}Y reactions;
- ^{120}I – ^{120}Te(p,n)^{120}I and ^{122}Te(p,3n)^{120}I reactions.

2.14. Uncertainties and Covariances for Recommended Cross Sections, A.V. Ignatyuk (Institute for Physics and Power Engineering (IPPE), Russia)

Large amounts of new experimental data characterizing and defining charged-particle induced reactions have been obtained over the previous decade. Significant progress has also been made in the theoretical simulation of the available data and systematics of the corresponding model parameters. These accumulated data present the opportunity to revise many previous recommendations concerning the monitor reaction cross sections and medical isotope production yields.

Furthermore, extensive developments have been made over a similar timescale in the analysis of data uncertainties, and comprehensive covariance matrices are an extremely important component of the present-day requests for recommended nuclear data. A brief review of the evaluation procedures developed at the IPPE was presented by Ignatyuk. These methods allow reasonable uncertainties to be derived during the evaluation process, along with covariances for much of the data related to medical isotope production. IPPE staff will carry out in-depth cross-section analyses and re-assessments of the monitor reactions and medical radioisotope production routes to assist in the re-assembly of the IAEA database.

3. Discussions

Participants focused their attention on the nuclear data needs formulated within IAEA report INDC(NDS)-0591, along with additional consideration of β^+ branching fractions and emission probabilities identified as inadequate within INDC(NDS)-0535. Excitation functions for the monitor reactions were initially discussed, and agreement was reached on the need to estimate and include uncertainty and covariance-based data in all of the recommended cross-section files that will be in the process of re-assessment, evaluation and assembly. “Assessment” is being used in this document to denote the compilation, selection and correction of the nuclear data prior to consideration for evaluation, while “evaluation” involves the derivation of recommended nuclear data through various considerations (e.g. weighted-mean analyses, spline fitting and modelling).

ACTION 3.1 on all cross-section assessors: A consensus was reached that systematic uncertainties in the cross-section data would always be greater than the equivalent systematic uncertainties of ~ 8% in the monitor reactions, and this assumption should be adhered to in any assessment/evaluation of the available data.
A number of additional reactions were also added to agreed components of the CRP work programme, based on some of the measurements and evaluations proposed initially by participants. Thus, the ^{nat}Ti(d,x)^{46}Sc and ^{nat}Ni(d,x)^{56,58}Co reactions were added to the list of monitor reactions to be assessed further at Debrecen and VUB, while various ^{64,67,68}Zn(n,x) reactions will be considered for the production of ^{67}Cu as a diagnostic γ emitter.

ACTION 3.2 on all cross-section assessors: Compile and assess existing data by the end of 2013.

Well-defined recommended decay data are required by the cross-section evaluators for their studies. These decay data are highly specific, and recommendations need to be available for adoption in the cross-section studies by June 2013.

ACTION 3.3 on decay-data evaluators: Complete decay-data evaluations for $t_{½}$ of ^{44}Ti (Kondev) and γ-ray emission probabilities for ^{52}Fe (Luca), ^{61}Cu (Bé), ^{63}Zn (Nichols) and ^{103}Pd **(**Nichols and Chechev**)** by the end of June 2013 for immediate consideration by cross-section evaluators.

ACTION 3.4 concerning cross-section and decay-data measurements: All agreed measurements should be completed and made available for presentation at the second research coordination meeting (i.e. by June/July 2014).

ACTION 3.5 on Scientific Secretary: Consult with EXFOR specialist/compilers concerning the timing information required from experimentalists when they undertake future measurements of activation cross sections if relevant timing constants are re-evaluated (e.g. $t_{1/2}$). Such information is relevant for adoption in the automatic correction system that is being developed by IAEA/NDS.

The evaluation methodology for comprehensive decay-scheme data was reviewed, and inadequacies were identified in the derivation of important Auger-electron data for future adoption in the specialized field of therapeutic micro-dosimetry. Kondev (ANL) reported that a suitable new data-generating approach based on a Monte-Carlo method is being developed to follow the vacancy propagations, together with transition rates calculated by means of different theoretical models. Several examples were discussed in terms of the detailed requirements for Auger-electron data in the CRP database. Collaboration involves scientists from Australia (ANU) and the USA (ANL). Consideration should be given to the adoption and implementation of such calculations during the evaluation of the decay data, along with the direct involvement of Kibedi (ANU) as a CRP participant.

ACTION 3.6 on Scientific Secretary: Consider inviting Kibedi (ANU, Australia) to participate in the existing CRP (**secretary's note** (20 December 2012): Kibedi has accepted an invitation from the IAEA-NDS to become a CRP participant, and will continue to work on the accurate quantification of Auger-electron emissions).

ACTION 3.7 on all attendees: Outline of the final technical report to be discussed and agreed during the second research coordination meeting (participants to prepare a draft contents list prior to the second RCM in June/July 2014).

4. Recommendations and primary actions

Various types of radionuclide were considered on the basis of their modes of production, decay characteristics, and existing and potential applications in nuclear medicine:

- monitor reactions,
- diagnostic γ-ray emitters,
- positron emitters,
- therapeutic α emitters,
- therapeutic electron and X-ray emitters.

Responsibility for individual data sets, future measurements and subsequent evaluations were defined separately in terms of either the specified excitation functions or comprehensive decay schemes, as shown in the relevant columns of Tables 1 to 5. Some of the resulting actions are required fairly promptly (e.g. Action 3.3 above, placed on particular radionuclides and decay-data evaluators), while others are longer term, constituting the important components of the final database for delivery and assembly in 2015/2016 at the envisaged conclusion of the on-going coordinated research project.

Proposed procedures for the initiation of the various work programmes were agreed in two different forms:

Cross sections

- Compile reaction data, and assess and deliver files before second RCM (June/July 2014). These EXCEL files should consist of (1) compiled data; (2) selected and corrected data; (3) rejected data
  - compile, assess, correct and select preferred data, providing reasons for data rejection;
  - provide full bibliographic lists in the style of IAEA Technical Reports Series no. 473;
  - send the files to Ignatyuk, with a copy to Capote (IAEA-NDS);
  - evaluated data produced by Ignatyuk will be sent to Tárkányi, with copy to Capote (IAEA-NDS);
  - yields will be calculated by Tárkányi from evaluated data provided by Ignatyuk.

Decay data

- Compile and evaluate decay data, and deliver before second RCM (June/July 2014)
  - evaluate and select preferred data, and provide reasons for data rejection;
  - provide full bibliographic lists in the style of IAEA Technical Reports Series no. 473;
  - send recommended data and comment files to Bé (LNHB), with copies to Capote (IAEA-NDS);
  - LNHB will implement the review process promptly, and all reviewers' comments and criticism will be taken into consideration by the responsible evaluator prior to final database release in ENSDF format.
- Auger-electron data for specific radionuclides require improved quantification with good accuracy, detail and confidence prior to incorporation in the recommended decay-data files
  - on-going studies to derive a suitable modeling code will continue (Kibedi and Kondev);
  - compile and evaluate Auger-electron data with respect to the modeling process, and provide recommended Auger-electron decay data before the third research coordination meeting (late 2015) for their insertion in the relevant files of the final database.

Some of the actions involve mixed combinations of measurements and assessments/evaluations. Under these circumstances, logic decrees that the measurements will be undertaken and reported prior to the final stage of full data assessment/evaluation.

4.1. *Monitor Reactions*

See Table 1.

Individual responsibilities and actions were established, as defined in Table 1. Thus, there are agreed needs for re-assessments of the excitation functions for the generation of ^{22}Na, ^{24}Na, ^{46}Sc, ^{48}V, ^{56}Co, ^{58}Co, ^{62}Zn, ^{63}Zn, ^{65}Zn, ^{66}Ga, ^{67}Ga and ^{96}Tc^{g+m}, coupled with new cross-section measurements to produce ^{48}V, ^{56}Co, ^{58}Co, ^{62}Zn, ^{63}Zn, ^{65}Zn, ^{66}Ga and ^{67}Ga. Both measurements and re-assessments were identified with the ^{nat}Ti(^{3}He,x)^{48}V and ^{nat}Ni(d,x)^{56,58}Co reactions, as were assessments of the available cross-section data for ^{nat}Ti(d,x)^{46}Sc and ^{nat}Mo(p,x)^{96}Tc^{g+m} reactions.

All of the monitor reactions quantified for IAEA-TECDOC-1211 require more rigorous definitions of the uncertainties along with covariances as a function of beam energy – these needs will be addressed during the course of the CRP.

Full decay-scheme evaluations were requested for ^{61}Cu, ^{62}Zn and ^{63}Zn.

4.2. *Diagnostic γ Emitters*

See Table 2.

Reactor production of ^{99}Mo/^{99}Tc^{m} generators has been the popular means of producing the most commonly used γ-ray emitting radionuclide for diagnostic purposes, and both the cross-section and decay data are well known. However, new data requirements have arisen as a consequence of recent efforts to produce this radionuclide by means of charged-particle accelerators rather than fission reactors. Various neutron-, proton-, deuteron-, photofission- and photoneutron-induced reactions need to be experimentally studied, along with the obligatory series of assessments or re-assessments.

Cross-section measurements and evaluations are required for the production of ^{64}Cu and ^{67}Cu, along with re-assessments of the excitation functions for specific reactions to produce ^{51}Cr, ^{111}In, ^{121}I, ^{123}Cs, ^{123}Xe, ^{200}Pb, ^{201}Pb and ^{202}Pb^{m}.

A decay-scheme evaluation was requested for ^{67}Cu, as well as the accurate derivation of well-resolved Auger-electron decay data for ^{99}Tc^{m} and ^{111}In.

4.3. *Positron Emitters*

See Table 3.

Significant requirements exist for re-assessments of the excitation functions for the production of ^{52}Fe, ^{55}Co, ^{61}Cu, ^{66}Ga, ^{68}Ga, ^{90}Nb, ^{72}As, ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m}, ^{110}In^{m} and ^{120}I, sometimes coupled with the need for new cross-section measurements of the ^{nat}Fe(p,x)^{55}Co, ^{61}Ni(p,n)^{61}Cu, ^{64}Zn(p,α)^{61}Cu, ^{68}Zn(p,n)^{68}Ga, ^{nat}Y(α,x)^{89}Zr, ^{93}Nb(p,x)^{90}Nb, ^{89}Y(α,x)^{90}Nb, ^{nat}Ge(p,xn)^{72}As, ^{75}As(p,3n)^{73}Se, ^{76}Se(p,n)^{76}Br, ^{77}Se(p,2n)^{76}Br and ^{89}Y(d,2n)^{89}Zr reactions.

Generator systems for the production of suitable β^{+} emitters were also considered. Measurements and assessments of the cross sections were judged to be required for the following:

- ^{62}Zn/^{62}Cu: ^{63}Cu(p,2n)^{62}Zn reaction,
- ^{68}Ge/^{68}Ga: ^{nat}Ga(p,xn)^{68}Ge, ^{69}Ga(p,2n)^{68}Ge and ^{71}Ga(p,4n)^{68}Ge reactions,

while re-assessments of available cross-section data were judged to be necessary for ^{44}Ti/^{44}Sc, ^{52}Fe/^{52}Mn^{m}, ^{72}Se/^{72}As, ^{82}Sr/^{82}Rb, ^{110}Sn/^{110}In^{m}, ^{118}Te/^{118}Sb, ^{122}Xe/^{122}I, ^{128}Ba/^{128}Cs and ^{140}Nd/^{140}Pr generators.

Decay-scheme evaluations were requested for ^{52}Fe, ^{64}Cu, ^{66}Ga, ^{72}As, ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m} and ^{120}I, along with the half-life of ^{44}Ti.

4.4. Therapeutic α Emitters

See Table 4.

Assessments of existing measured cross-section data for ^{232}Th(p,x) production of ^{225}Ra, ^{225}Ac and impurity ^{227}Ac, and ^{226}Ra(p,2n) production of ^{225}Ac were recommended. Identical demands were also made concerning ^{230}U production from the ^{231}Pa(p,2n), ^{231}Pa(d,3n) and ^{232}Th(p,3n)^{230}Pa(β^-)^{230}U reactions, and the ^{232}Th(p,x)^{227}Th reaction to initiate the ^{227}Th(α)^{223}Ra(α) decay chain.

Full decay-scheme evaluations were requested for all radionuclides constituting the ^{230}U decay chain: ^{230}U(α)^{226}Th(α)^{222}Ra(α)^{218}Rn(α)^{214}Po(α)^{210}Pb(β^-)^{210}Bi(β^-)^{210}Po(α)^{206}Pb(stable).

4.5. Therapeutic Electron and X-ray Emitters

See Table 5.

Assessments of reactions suitable for the direct production of ^{131}Cs and parent ^{131}Ba were recommended, while measurements and assessments of the production of ^{178}Ta by means of ^{176}Hf(α,2n)^{178}W(EC)^{178}Ta and ^{nat}Hf(p,x) need to be undertaken.

A decay-scheme evaluation was requested for ^{103}Pd, along with the accurate derivation of well-resolved Auger-electron decay data for ^{103}Pd and ^{178}Ta.

At the end of the discussions outlined above and defined more precisely in Tables 1 to 5, Capote is to establish suitable links to all relevant neutron-induced production data, and implement additional improvements to the Medical Portal of the IAEA Nuclear Data Section.

Table 1: Monitor reactions

Cross sections	Decay data	Agreed responsibilities, and actions
$^{27}Al(p,x)^{22,24}Na$	–	**ACTION**: LANL (re-assess up to 800 MeV)
$^{27}Al(d,x)^{22,24}Na$		**ACTION**: Debrecen / VUB (re-assess)
$^{27}Al(^{3}He,x)^{22,24}Na$		**ACTION**: Debrecen / VUB (re-assess)
$^{27}Al(\alpha,x)^{22,24}Na$		**ACTION**: Kim (measure); **ACTION**: Debrecen / VUB (assess)
$^{nat}Ti(d,x)^{46}Sc$	–	**ACTION**: Debrecen / VUB (re-assess)
$^{nat}Ti(^{3}He,x)^{48}V$	–	**ACTION**: Lebeda (measure and re-assess up to 46 MeV)
$^{nat}Ni(d,x)^{56,58}Co$	–	**ACTION**: Debrecen / VUB (measure and re-assess)
$^{nat}Cu(p,x)^{58}Co$	–	**ACTION**: Kim (measure); **ACTION**: LANL (measure and assess up to 100 MeV)
$^{nat}Cu(p,x)^{62,63,65}Zn$		**ACTION**: Kim (measure); Debrecen / VUB (measure and re-assess)
$^{nat}Cu(d,x)^{62,63,65}Zn$		**ACTION**: Debrecen / VUB (measure and re-assess)
$^{nat}Cu(\alpha,x)^{66,67}Ga$, ^{65}Zn		**ACTION**: Kim (measure and re-assess)
$^{nat}Mo(p,x)^{96}Tc^{g+m}$	–	**ACTION**: Debrecen / VUB / Lebeda (assess)
–	^{61}Cu	evaluate ^{61}Cu decay scheme (**ACTION**: Bé)
–	^{62}Zn	evaluate ^{62}Zn decay scheme, priority 2 (see ENSDF, 2012)
–	^{63}Zn	evaluate ^{63}Zn decay scheme (**ACTION**: Nichols)
previously evaluated cross sections	–	**ACTION**: all monitor reaction cross sections included in IAEA-TECDOC-1211 but not listed above will be re-evaluated by Debrecen / VUB to include uncertainties and covariances.

Table 2: Diagnostic γ emitters

Cross sections	Decay data	Agreed responsibilities, and actions
$^{90}Zr(n,p)^{90}Y^{g+m}$	–	**ACTION**: ITA / Nagai (measure) - **ACTION**: ITA (assess) - see also IRDFF (http://www-nds.iaea.org/IRDFF) and IAEA Technical Reports Series No. 473.
$^{100}Mo(n,2n)^{99}Mo$	–	**ACTION**: ITA / Nagai (assess)
$^{100}Mo(p,2n)^{99}Tc^{g+m}$		**ACTION**: Lebeda (measure); **ACTION**: ITA (assess)
$^{100}Mo(p,pn)^{99}Mo$		**ACTION**: Lebeda (measure); **ACTION**: ITA (assess)
$^{100}Mo(d,3n)^{99}Tc^{g+m}$		**ACTION**: Lebeda / ITA (assess)
$^{100}Mo(d,p2n)^{99}Mo$		**ACTION**: Lebeda / ITA (assess)
$^{100}Mo(\gamma,n)^{99}Mo$		**ACTION**: Naik / Kim (measure and assess)
$^{238}U(\gamma,f)^{99}Mo$		**ACTION**: Naik (measure and assess)
$^{68}Zn(\gamma,p)^{67}Cu$	–	**ACTION**: Naik / Kim (measure and assess)
$^{67}Zn(n,p)^{67}Cu$		**ACTION**: Nagai (measure); **ACTION**: ITA (assess) - see also IRDFF (http://www-nds.iaea.org/IRDFF) and IAEA Technical Reports Series No. 473.
$^{68}Zn(n,x)^{67}Cu$		**ACTION**: Nagai (measure); **ACTION**: ITA (assess)
$^{64}Zn(n,p)^{64}Cu$		**ACTION**: Nagai (measure); **ACTION**: ITA (assess) - see also IRDFF (http://www-nds.iaea.org/IRDFF) and IAEA Technical Reports Series No. 473, and INDC(NDS)-0526, August 2008
$^{112}Cd(p,2n)^{111}In$	–	**ACTION**: Debrecen / VUB (assess)
$^{124}Xe(p,x)^{121}I$	–	**ACTION**: Debrecen / VUB (assess)
$^{124}Xe(p,2n)^{123}Cs$	–	**ACTION**: Debrecen / VUB (assess)
$^{124}Xe(p,pn)^{123}Xe$		**ACTION**: Debrecen / VUB (assess)
$^{51}V(p,n)^{51}Cr$	–	**ACTION**: Debrecen (re-assess all noted production routes of ^{51}Cr)
$^{nat}Fe(p,x)^{51}Cr$		**ACTION**: Kim (measure and assess)

Table 2: Diagnostic γ emitters (cont'd)

Cross sections	Decay data	Agreed responsibilities, and actions
^{203}Tl(p,2n)^{202}Pb^{m}	–	**ACTION**: Debrecen / VUB (re-assess)
^{203}Tl(p,3n)^{201}Pb		**ACTION**: Debrecen / VUB (re-assess)
^{203}Tl(p,4n)^{200}Pb		**ACTION**: Debrecen / VUB (re-assess)
^{nat}W(α,x)^{186,188}Re	–	**ACTION**: Kim (measure and assess)
–	^{67}Cu	**ACTION**: Kondev (measure, and evaluate decay scheme)
–	^{99}Tc^{m}	**ACTION**: Kibedi and Kondev (Auger-electron data)
–	^{111}In	**ACTION**: Kibedi and Kondev (Auger-electron data)

Table 3: Positron emitters

Cross sections	Decay data	Agreed responsibilities, and actions
^{55}Mn(p,4n)^{52}Fe	–	**ACTION**: Lahore (assess)
^{nat}Ni(p,x)^{52}Fe		**ACTION**: Lahore (assess)
^{52}Cr(^{3}He,3n)^{52}Fe		**ACTION**: Lahore (assess)
^{58}Ni(p,α)^{55}Co	–	**ACTION**: Lahore (assess)
^{54}Fe(d,n)^{55}Co		**ACTION**: Lahore (assess)
^{56}Fe(p,2n)^{55}Co		**ACTION**: Lahore (assess)
^{nat}Fe(p,x)^{55}Co		**ACTION**: Kim (measure); **ACTION**: Lahore (assess)
^{61}Ni(p,n)^{61}Cu	–	**ACTION**: Jülich (measure and assess)
^{64}Zn(p,α)^{61}Cu		**ACTION**: Lebeda (measure and assess)
^{66}Zn(p,n)^{66}Ga	–	**ACTION**: Lahore (assess)
^{63}Cu(α,n)^{66}Ga		**ACTION**: Lahore (assess)
^{68}Zn(p,n)^{68}Ga	–	**ACTION**: Jülich (measure and assess)
^{65}Cu(α,n)^{68}Ga		**ACTION**: Jülich (assess)
^{93}Nb(p,x)^{90}Nb	–	**ACTION**: Kim (measure and assess)
^{89}Y(α,x)^{90}Nb		**ACTION**: Kim (measure and assess)
^{89}Y(α,x)^{89}Zr		**ACTION**: Kim (measure and assess)
^{nat}Ge(p,xn)^{72}As	–	**ACTION**: Jülich (measure); **ACTION**: Lahore (assess)

Table 3: Positron emitters (cont'd)

Cross sections	Decay data	Agreed responsibilities, and actions
$^{75}As(p,3n)^{73}Se$	–	**ACTION**: Lebeda (measure); **ACTION**: Lahore (assess)
$^{72}Ge(\alpha,3n)^{73}Se$		**ACTION**: Lahore (assess)
$^{76}Se(p,n)^{76}Br$	–	**ACTION**: Jülich (measure); **ACTION**: Lahore (assess)
$^{77}Se(p,2n)^{76}Br$		**ACTION**: Jülich (measure); **ACTION**: Lahore (assess)
$^{75}As(\alpha,3n)^{76}Br$		**ACTION**: Lahore (assess)
$^{86}Sr(p,n)^{86}Y$	–	**ACTION**: Lahore (assess)
$^{88}Sr(p,3n)^{86}Y$		**ACTION**: Lahore (assess)
$^{85}Rb(\alpha,3n)^{86}Y$		**ACTION**: Lahore (assess)
$^{89}Y(p,n)^{89}Zr$	–	**ACTION**: ITA (assess)
$^{89}Y(d,2n)^{89}Zr$		**ACTION**: Lebeda (measure and assess)
$^{94}Mo(p,n)^{94}Tc^{m}$	–	**ACTION**: ITA (assess)
$^{92}Mo(\alpha,x)^{94}Tc^{m}$		**ACTION**: ITA (assess)
$^{110}Cd(p,n)^{110}In^{m}$	–	**ACTION**: Debrecen / VUB (assess)
$^{120}Te(p,n)^{120}I$	–	**ACTION**: Lahore (assess)
$^{122}Te(p,3n)^{120}I$		**ACTION**: Lahore (assess)
–	^{52}Fe	evaluate, and assess if new measurements required, priority 3 (**ACTION**: Luca – evaluate decay scheme)
–	^{64}Cu	discrepancy in the intensity of weak gamma line (**ACTION**: Bé – re-evaluate decay scheme)
–	^{66}Ga	determine positron intensities and evaluate, priority 1 (**ACTION**: Kondev – measure, and evaluate decay scheme)
–	^{72}As	determine positron intensities and evaluate, priority 2 (no volunteer)

Table 3: Positron emitters (cont'd)

Cross sections	Decay data	Agreed responsibilities, and actions
–	^{73}Se	determine positron intensities and evaluate, priority 2 (**ACTION**: Nichols – evaluate decay scheme)
–	^{76}Br	determine positron intensities and evaluate, priority 3 (**ACTION**: Nichols – evaluate decay scheme)
–	^{86}Y	PET analogue of therapeutic ^{90}Y; determine positron intensities and evaluate, priority 1 (**ACTION**: Kondev - measure, and evaluate decay scheme)
–	^{89}Zr	evaluate ^{89}Zr decay scheme, priority 3 (**ACTION**: Nichols)
–	$^{94}Tc^{m}$	PET analogue of therapeutic $^{99}Tc^{m}$; evaluate $^{94}Tc^{m}$ decay scheme, priority 2 (**ACTION**: Nichols)
–	^{120}I	evaluate ^{120}I decay scheme, priority 3 (**ACTION**: Nichols)

Table 3: Positron emitters (cont'd.): generators

Generator	Cross sections	Decay data	Agreed responsibilities, and actions
$^{62}Zn/^{62}Cu$		–	PET analogue of therapeutic ^{67}Cu
	$^{63}Cu(p,2n)^{62}Zn$		**ACTION**: Debrecen / VUB (measure and assess)
$^{68}Ge/^{68}Ga$		–	PET analogue of proposed/new therapeutic ^{67}Ga
	$^{nat}Ga(p,xn)^{68}Ge$		**ACTION**: Debrecen / VUB (measure and assess)
	$^{69}Ga(p,2n)^{68}Ge$		**ACTION**: Debrecen / VUB (measure and assess)
	$^{71}Ga(p,4n)^{68}Ge$		**ACTION**: Debrecen / VUB (measure and assess)
$^{72}Se/^{72}As$	$^{75}As(p,4n)^{72}Se$	–	**ACTION**: LANL (assess)
	$^{nat}Br(p,x)^{72}Se$		**ACTION**: LANL (assess)
$^{82}Sr/^{82}Rb$	$^{nat}Rb(p,xn)^{82}Sr$ $^{85}Rb(p,4n)^{82}Sr$	–	**ACTION**: LANL (assess)
$^{52}Fe/^{52}Mn^{m}$	$^{55}Mn(p,4n)^{52}Fe$ $^{nat}Ni(p,x)^{52}Fe$ $^{52}Cr(^{3}He,3n)^{52}Fe$	–	**ACTION**: Lahore (assess)
$^{110}Sn/^{110}In^{m}$	Main reactions leading to the parent nucleus	–	PET analogue of therapeutic ^{111}In and $^{114}In^{m}$; **ACTION:** Debrecen / VUB (assess)
$^{128}Ba/^{128}Cs$	Main reactions leading to the parent nucleus	–	PET analogue of proposed/new therapeutic ^{131}Cs; **ACTION**: Debrecen / VUB (assess)
$^{122}Xe/^{122}I$	Main reactions leading to the parent nucleus	–	PET analogue of therapeutic ^{123}I, ^{125}I and ^{131}I; **ACTION**: Debrecen / VUB (assess)
$^{118}Te/^{118}Sb$	Main reactions leading to the parent nucleus	–	PET analogue of proposed/new therapeutic ^{117}Sb and ^{119}Sb; **ACTION**: Debrecen / VUB (assess)
$^{140}Nd/^{140}Pr$	Main reactions leading to the parent nucleus	–	**ACTION**: LANL (assess)
$^{44}Ti/^{44}Sc$	Main reactions leading to the parent nucleus	half-life of ^{44}Ti	**ACTION**: Jülich (assess cross sections); **ACTION**: Kondev (evaluate ^{44}Ti half-life)

Table 4: Therapeutic α emitters

Cross sections	Decay data	Agreed responsibilities, and actions
$^{229}Th(\alpha)^{225}Ra(\beta^-)^{225}Ac(\alpha)$ decay chain to ^{213}Bi:	–	Decay chain recently reevaluated in Actinide decay data CRP (to be published).
$^{232}Th(p,x)^{225}Ra$		**ACTION**: LANL (assess)
$^{232}Th(p,x)^{225}Ac$		**ACTION**: LANL (assess)
$^{226}Ra(p,2n)^{225}Ac$		**ACTION**: LANL (assess)
$^{232}Th(p,x)^{227}Ac$		**ACTION**: LANL (assess)
$^{230}U(\alpha)^{226}Th(\alpha)$ decay chain:	–	
$^{231}Pa(d,3n)^{230}U$		**ACTION**: Lebeda (assess)
$^{231}Pa(p,2n)^{230}U$		**ACTION**: Lebeda (assess)
$^{232}Th(p,3n)^{230}Pa(\beta^-)^{230}U$		**ACTION**: Lebeda (assess)
$^{227}Th(\alpha)^{223}Ra(\alpha)$ decay chain	–	
$^{232}Th(p,x)^{227}Th$		**ACTION**: LANL (assess)
–	^{230}U decay chain	**ACTION**: Luca and Bé (evaluate decay schemes of radionuclides in ^{230}U decay chain: $^{230}U(\alpha)^{226}Th(\alpha)^{222}Ra(\alpha)^{218}Rn(\alpha)^{214}Po(\alpha)^{210}Pb(\beta^-)^{210}Bi(\beta^-)^{210}Po(\alpha)^{206}Pb$(stable))

Table 5: Electron and X-ray emitters

Cross sections	Decay data	Agreed responsibilities, and actions
$^{130}Ba(n,\gamma)^{131}Ba(EC)^{131}Cs$	–	**ACTION**: Nagai (assess)
$^{131}Xe(p,n)^{131}Cs$	–	**ACTION**: Debrecen / VUB (measure and assess)
$^{133}Cs(p,3n)^{131}Ba(EC)^{131}Cs$	–	**ACTION**: Debrecen / VUB (measure and assess)
$^{176}Hf(\alpha,2n)^{178}W(EC)^{178}Ta$	–	**ACTION**: Kim (measure and assess)
$^{nat}Hf(p,x)^{178}Ta$	–	**ACTION**: Kim (measure and assess)
–	^{178}Ta	**ACTION**: Kibedi and Kondev (Auger-electron data)
–	^{103}Pd	evaluate ^{103}Pd decay scheme, priority 1 (**ACTION**: Chechev (evaluate decay scheme) and Nichols (review evaluation); **ACTION**: Kibedi and Kondev (Auger-electron data))
–	–	Capote, **ACTION**: establish link to neutron-induced production data, and implement additional changes to IAEA Medical Portal

5. Concluding remarks

The contents of this report constitute a summary of the agreed activities of participants involved in a newly launched IAEA coordinated research project dedicated to the derivation of improved cross-section and decay data for radionuclides identified with nuclear medicine, diagnostic procedures and therapeutic applications. Participants reviewed the recommendations of a consultants' meeting held in June 2011 to discuss "Improvements in Charged-Particle Monitor Reactions and Nuclear Data for Medical Isotope Production" (IAEA report INDC(NDS)-0591), and also considered other related pronouncements including improved nuclear data for PET radionuclides (IAEA report INDC(NDS)-0535) and intermediate-term requirements (IAEA report INDC(NDS)-0596). Both cross-section and decay-data measurements and evaluations were agreed in order to improve the quality of such data in the assembly of a suitable database dedicated to nuclear medicine.

Responsibilities and actions were agreed during the course of the meeting as given in Sections 3 and 4, and detailed within Tables 1 to 5 in terms of assigned responsibilities for nuclear data measurements and assessments/evaluations. Work programmes were discussed and formulated on an individual basis, and specific deadlines were set leading up the second research coordination meeting scheduled for some time in either June or July 2014.

1st Research Coordination Meeting on

"Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production"

IAEA Headquarters, Vienna, Austria
3 – 7 December 2012

Meeting Room MOE75

Provisional AGENDA

Monday, 3 December

08:30 - 09:30	**Registration** (IAEA Registration desk, Gate 1)
09:30 - 10:00	**Opening Session** Welcoming address –Meera Venkatesh (Director NAPC) Introductory Remarks – Roberto Capote Noy Election of Chairman and Rapporteur Adoption of Agenda
10:00 - 10:45	**Administrative and Financial Matters related to participants** Coffee break
10:45 - 12:30	**Session 1:** Presentation of Research Proposals and discussion (Nichols, Bé, *30-40 min each*)
12:30 – 14:00	**Lunch**
14:00 – 18:00	**Session 1:** Presentation of Research Proposals and discussion (Kondev, Luca, Nortier, *30-40 min each*)

Coffee break (as needed)

Tuesday, 4 December

09:00 - 12:30	**Session 1:** Presentation of Research Proposals and discussion (Spahn, Lebeda, Tarkanyi, *30-40 min each*) *Coffee break (as needed)*
12:30 - 14:00	**Lunch**
14:00 – 18:00	**Session 1:** Presentation Discussion of Research Proposals and Presentations (Naik, Nagai, Carlson, *30-40 min each*) *Coffee break (as needed)*
19:00	***Dinner at a restaurant in the city*** (see separate information in folder)

Wednesday, 5 December

09:00 - 12:30 **Session 1:** Discussion of Research Proposals and Presentation (Kim, Ignatyuk, Hussain, *30-40 min each*)

Coffee break (as needed)

12:30 - 14:00 **Lunch**

14:00 – 18:00 **Session 2:** Discussion of expected outputs and research coordination (reaction data)

Coffee break (as needed)

Thursday, 6 December

09:00 - 12:30 **Session 2:** Discussion of expected outputs and research coordination (structure and decay data**)**

Coffee break (as needed)

12:30 - 14:00 **Lunch**

14:00 – 18:00 **Drafting of the Summary Report of the Meeting**

Coffee break (as needed)

Friday, 7 December

09:00 - 16:00 **Review of the Meeting Summary Report**

Coffee break (as needed)

16:00 **Closing of the Meeting**

1st Research Coordination Meeting on
"Nuclear data for charged-particle monitor reactions and medical isotope production"
IAEA, Vienna
3-7 December 2012

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