

Raport stiintific sintetic

privind implementarea proiectului in perioada octombrie 2011 – decembrie 2013

Denumirea proiectului: Reactii nucleare induse de deuteroni la energii joase si medii:

Analiza consistenta a mecanismelor de reactii directe si statistice

[http://tandem.nipne.ro/~dante/projects/PN2P3_0450/index.html]

Cod: PN-II-ID-PCE-2011-3-0450, Director: M. Avrigeanu, <http://www.researcherid.com/rid/B-6068-2011>

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Etapa unica 2011: Analiza consistenta a interactiilor deuteronilor cu nuclee de masa medie la energii joase , cu luarea in considerare a interactiilor directe

Rezultatele obtinute in cadrul acestei etape a proiectului de fata, urmarind analiza consistenta a interactiilor deuteronilor cu nuclee de masa medie la energii joase , cu luarea in considerare a interactiilor directe, au contribuit in prima instanta la definitivarea formei ce a fost transmisa pentru publicarea in **'Proceedings'** ulterior sustinerii unei contributii¹ orale la *'Third Int. Workshop on Compound Nuclear Reactions and Related Topics, Sept. 19-23, 2011, Prague'*, cu urmatorul rezumat:

„**Abstract.** An extended analysis of the reaction mechanisms involved within deuteron interaction with nuclei is presented. An increased attention is devoted to the breakup mechanism, all its components, namely the elastic, inelastic (fusion), and total breakup being carefully considered. Next, the direct reactions represented by the stripping and pick-up mechanisms are discussed. Finally, the pre-equilibrium and compound-nucleus contributions, corrected for the breakup, stripping, and pick-up decrease of the total reaction cross section, complete the deuteron-induced reaction cross section analysis. The overall agreement between the measured data and model calculations validates the description of nuclear mechanisms taken into account for the deuteron-nucleus interaction.”

In timp ce lucrarea mentionata mai sus a fost realizata pe baza a doua proiecte nationale, datorita activitatii consistente desfasurata si anterior demararii proiectului de fata, ponderea principala a etapei de fata a fost reprezentata de finalizarea unei lucrari asupra importantei procesului de rupere (*'breakup'* - BU) a deuteronilor. Semnificatia acestui tip de interactie directa, fata de procesul statistic al fisiunii nucleare considerat pana in prezent ca primordial in zona actinidelor, a format obiectul unei lucrari publicate ca raport electronic², transmisa spre publicare intr-un jurnal ISI cu finalizarea indicata in raportul pe anul 2012.

Cele doua lucrari prezentate mai sus au format obiectul a doua rapoarte sustinute in cadrul *JEFF/EFF Meeting, 28 Nov. - 2 Dec. 2011, OECD/NEA, Issy-les-Moulineaux, France* (<http://www.oecd->

¹ M. Avrigeanu, V. Avrigeanu, and F.L. Roman, *Deuteron-induced reaction mechanisms at low energies*, Third Int. Workshop on Compound Nuclear Reactions and Related Topics, Sept. 19-23, 2011, Prague, EPJ Web of Conf. **21**, 07003 (2012); www-ucjf.troja.mff.cuni.cz/cnr11/presentations_dir/avrigeanu_m.pdf.

² M. Avrigeanu, V. Avrigeanu, and A.J. Koning, <http://arxiv.org/abs/1112.1832>; submitted (Phys. Rev. C).

nea.org/dbdata/meetings/nov2011/), a caror prezentare^{3,4} a fost realizata pe baza proiectului de fata. In timp ce prima prezentare³ a supus atentiei rezultatele ce formeaza obiectul lucrarii anterioare², a doua prezentare⁴ a fost dedicata aspectelor de interes si pentru descrierea interactiilor neutronilor ce rezulta din procesul de rupere a deuteroniilor (*BU-nucleons*). Ambele lucrari au primit o apreciere pozitiva si au reprezentat baza pentru includerea echipei de cercetare a proiectului de fata in cadrul acordului cu nr. F4E-FPA-168/2011 de tip „*Framework Partnership Agreement*” (FPA) al unui consortiu, incluzand grupul din IFIN-HH, cu agentia **Fusion for Energy** (F4E, <http://fusionforenergy.europa.eu/>). Din pacate finantarea acestui acord va fi redusa la un nivel simbolic de catre costurile marite semnificativ ale proiectului ITER (<http://www.iter.org/>), astfel incat sustinerea proiectului de fata – corelat strict cu un *task*’ 5.2 al acordului F4E-FPA-168/2011 – va fi esentiala pentru o contributie marita la atingerea obiectivelor necesare realizarii proiectului ITER. Au fost insa astfel probate interesul si capacitatea de atragere a unor fonduri externe.

Etapa unica 2012: Analiza componentelor sectiunii eficace ale procesului de ‘breakup’ pentru interactiunea deuteroniilor cu nuclee de masa medie la energii incidente $E < 60$ MeV

Rezultatele obtinute in cadrul acestei etape a proiectului de fata, urmarind analiza consistenta a interactiilor deuteroniilor cu nuclee de masa medie la energii joase , cu luarea in considerare a interactiilor directe, au contribuit in prima instanta la realizarea formei finale a unei lucrari⁵ asupra importantei procesului de rupere (BU) a deuteroniilor fata de procesul statistic al fisiunii nucleare, considerat anterior ca fiind primordial in zona actinidelor, cu urmatorul rezumat:

„**Abstract.** The dominance of the deuteron breakup mechanism around the Coulomb barrier is shown by an analysis of the $^{231}\text{Pa}(d,3n)^{230}\text{U}$ reaction excitation function, while the same attribute was found within a former assessment for the deuteron-induced fission. The present alternative result is obtained by taking into account, in addition to pre-equilibrium and compound-nucleus processes, the opposite effects of deuteron breakup, namely the decrease of the deuteron total reaction cross section, and the inelastic-breakup enhancement of various deuteron-induced reaction channels.”

Ponderea principala a etapei de fata a reprezentat-o realizarea unei contributii⁶ orale la conferinta traditionala asupra mecanismelor de reactii nucleare ‘*13th Int. Conf. on Nuclear Reaction Mechanisms, 11-15 June 2012, Varenna, Italy*’, asupra sistematicii interactiei deuteroniilor la energii joase, cu urmatorul rezumat:

³ M. Avrigeanu, *Consistent analysis of deuteron interaction at low energy triggered by the direct reaction account*, JEFF/EFF Meeting, 28 November - 2 December 2011, OECD/NEA, Issy-les-Moulineaux, France, http://www.oecd-nea.org/html/dbdata/nds_effdoc/effdoc-1153.pdf .

⁴ V. Avrigeanu, *Isomeric cross sections of fast neutron induced reactions on ^{197}Au* , JEFF/EFF Meeting, 28 November - 2 December 2011, OECD/NEA, Issy-les-Moulineaux, France, http://www.oecd-nea.org/html/dbdata/nds_effdoc/effdoc-1152.pdf .

⁵ M. Avrigeanu, V. Avrigeanu, and A.J. Koning, *Investigation of deuteron breakup and deuteron-induced fission on actinide nuclei at low incident energies*, Phys. Rev. C **85**, 034603 (2012).

⁶ M. Avrigeanu and V. Avrigeanu, *Consistent analysis of all-inclusive deuteron-induced reactions at low energies*, Proc. *13th Int. Conf. on Nuclear Reaction Mechanisms, 11-15 June 2012, Varenna, Italy*, CERN Proceedings-2012-002, pp.187-193.; <http://www.fluka.org/Varenna2012/>.

„**Abstract.** An extended analysis of the reaction mechanisms involved within deuteron interaction with nuclei, namely the breakup, stripping, pick-up, pre-equilibrium emission, as well as the evaporation from fully equilibrated compound nucleus, is presented. The overall agreement between the measured data and model calculations validates the description of nuclear mechanisms taken into account for the deuteron-nucleus interaction.”

Deoarece o particularitate a reacțiilor induse de deuteroni la energii joase de maxim interes actual o reprezintă activarea în principal a unor stări izomere, eliminarea unor semne de întrebare specifice acestui tip de activare s-a impus în vederea devenirii posibile a obținerii unor concluzii finale consistente. Astfel, este binecunoscută dependența principală a secțiunilor de activare a stărilor izomere de mărimea momentului nuclear efectiv de inerție ce determină dependența de moment cinetic a densității de nivele nucleare. Principalele referințe asupra acestui subiect au fost trecute în revistă, în vederea evidentierii modului în care este necesară corelarea diferitelor modele actuale adoptate pentru această mărime, într-o lucrare⁷ publicată cu următorul rezumat:

„**Abstract.** Recent accurate data obtained for the isomeric cross section of the $^{197}\text{Au}(n,2n)$ reaction provide a valuable opportunity to consider the question of the effective moment of inertia of the nucleus within a local consistent model analysis of all available reaction data for the ^{197}Au target nucleus. Thus, a definite proof of a moment of inertia equal to that of the rigid-body has been obtained for ^{196}Au nucleus, while indications infer about half the rigid-body for ^{194}Ir .”

Complexitatea mecanismelor de reacție implicate de către deuteroni la energii joase au impus participarea la conferințe internaționale dedicate unei tematici mai largi a proceselor nucleare la aceste energii. În acest context s-a încadrat o prezentare⁸ invitată la *‘Carpathian Summer School of Physics 2012: Exotic Nuclei and Nuclear/Particle Astrophysics (IV) - From nuclei to stars’*, cu următorul rezumat:

„**Abstract.** The high precision of recent measurements for low-energy α -particle elastic-scattering as well as induced-reaction data makes possible the understanding of actual limits and possible improvement of the global optical model potentials parameters. Involvement of recent optical potentials for reliable description of both the elastic scattering and emission of α -particles, of equal interest for nuclear astrophysics (NA) and nuclear technology (NT) for fusion devices, is discussed in the present work.”

În același sens, al interesului ultimelor două subiecte pentru proiectele de fuziune nucleară, rezultate obținute în cadrul proiectului de față au format obiectul și a două lucrări^{9,10} prezentate în cadrul

⁷ M. Avrigeanu, V. Avrigeanu, M. Diakaki, and R. Vlastou, *Isomeric cross sections of fast-neutron induced reactions on ^{197}Au* , Phys. Rev. C **85**, 044618 (2012).

⁸ M. Avrigeanu and V. Avrigeanu, *α -particle Optical Potentials for Nuclear Astrophysics and Nuclear Technology*, [AIP Conf. Proc. 1498 \(2012\) 169-177](#); doi: 10.1063/1.4768492.

⁹ M. Avrigeanu, *Progress on the analysis of all-inclusive deuteron-induced reactions at low energies* (EFFDOC-1178), JEFF/EFF Meeting, 27-29 November 2012, OECD/NEA, Issy-les-Moulineaux, France, http://www.oecd-nea.org/html/dbdata/nds_effdoc/effdoc-1178.pdf.

¹⁰ V. Avrigeanu, *Progress on the analysis of alpha-particle optical potentials at low energies* (EFFDOC-1177), JEFF/EFF Meeting, 27-29 November 2012, OECD/NEA, Issy-les-Moulineaux, France, http://www.oecd-nea.org/html/dbdata/nds_effdoc/effdoc-1177.pdf.

JEFF/EFF Meeting, 27-29 November 2012, OECD/NEA, France. Ambele lucrari au primit o apreciere pozitiva care a asigurat continuarea activitatii echipei de cercetare a proiectului de fata in cadrul acordului F4E-FPA-168/2011 al unui consorțiului incluzand grupul din IFIN-HH cu agentia *Fusion for Energy*.

Etapa unica 2013: Analiza consistenta a interactiunii deuteroniilor cu nucleele $^{54,56}\text{Fe}$ la energii joase

Activitatea 1.1. Analiza componentelor sectiunii eficace ale procesului de 'breakup' pentru interactiunea deuteroniilor cu nucleele $^{54,56}\text{Fe}$ (prezentare orala la conferinta internationala).

Rezultatele obtinute in cadrul acestei activitati a proiectului de fata, urmarind analiza consistenta a interactiilor deuteroniilor cu nuclee de masa medie la energii joase, cu luarea in considerare a interactiilor directe, au contribuit in prima instanta la realizarea unei lucrari invitate¹¹, prezentata oral, asupra importantei procesului de rupere (BU) a deuteroniilor fata de procesele statistice inclusiv in cazul particular al interactiunilor deuteroniilor cu nucleele $^{54,56}\text{Fe}$, cu urmatorul rezumat:

„**Abstract.** An extended analysis of reaction mechanisms involved in deuterons interaction with target nuclei from 27Al till 231Pa, at incident energies up to 60 MeV, is presented. Increased attention is devoted to direct processes, concerning the breakup, stripping, and pick-up contributions to the deuteron activation cross sections. Finally, the pre-equilibrium and evaporation cross sections, corrected for the initial flux leakage towards direct processes, have completed the deuteron interaction analysis. The overall agreement of the measured data and model calculations proves the correctness of nuclear mechanism description.”

Activitatea 1.2. Analiza sectiunilor eficace de activare ale deuteroniilor cu nucleele $^{54,56}\text{Fe}$ (lucrare publicata in jurnal ISI).

Ponderea principala a etapei de fata a reprezentat-o realizarea a doua lucrari^{12,13} asupra sectiunilor eficace de reactie ale deuteroniilor la energii joase, cu urmatoarele rezumate:

„**Abstract.** The activation cross sections of (d,p), (d,2n), (d,2np+nd+t), (d,2na), and (d,pa) reactions on 93Nb were measured in the energy range from 1 to 20 MeV using the stacked-foil technique. Then, within a simultaneous analysis of elastic--scattering and reaction data, the available elastic-scattering data analysis was carried out in order to obtain the optical potential for reaction cross-section calculations. Particular attention is paid to description of the breakup mechanism and direct reaction stripping and pick--up, followed by pre-equilibrium and compound--nucleus calculations. The measured cross sections as well as all available deuteron activation data of 93Nb were

¹¹ M. Avrigeanu and V. Avrigeanu, [Direct processes effects on deuteron activation cross sections](#), in *Proc. XX Int. School on Nuclear Physics, Neutron Physics and Applications, 16 - 22 September 2013, Varna, Bulgaria (Journal of Physics: Conference Series, in press).*

¹² M. Avrigeanu, V. Avrigeanu, P. Bem, U. Fischer, M. Honusek, A.J. Koning, J. Mrazek, E. Simeckova, M. Stefanik, and L. Zavorka, *Low energy deuteron-induced reactions on 93Nb*, Phys. Rev. C **88**, 014612 (2013). DOI: [10.1103/PhysRevC.88.014612](https://doi.org/10.1103/PhysRevC.88.014612)

¹³ M. Avrigeanu and V. Avrigeanu, [Consistent analysis of the nuclear reaction mechanisms involved in the deuteron-induced activations at low and medium energies](#), Nuclear Data Sheets (in press).

compared with results of local model calculations carried out using the codes FRESKO and STAPRE-H, and both default and particular predictions of the code TALYS-1.4 and TENDL-2012 evaluated data.”,

respectiv

„**Abstract.** A complete analysis of the nuclear reaction mechanisms involved within Fe(d,x)55Co reaction, i.e. the breakup, stripping, pick-up, pre-equilibrium emission, and evaporation from fully equilibrated compound nucleus, is presented in order to highlight the importance of direct mechanisms that are not appropriately considered in the evaluation procedure. The overall agreement between the measured data and model calculations confirms the correctness of nuclear mechanism description taken into account stressing out the omissions of the evaluation procedures.”

Ca urmare a interesului acestor subiecte pentru proiectele de fuziune nucleara, rezultate obtinute in cadrul proiectului de fata au fost incluse si in cadrul a patru rapoarte^{14,15} prezentate in cadrul *JEFF/EFF Meetings, 17-19 Aprilie 2013 and 25-29 November 2013*, OECD/NEA, France. Aceste lucrari au primit o apreciere pozitiva si au asigurat continuarea activitatii echipei de cercetare a proiectului de fata in cadrul acordului F4E-FPA-168/2011 al consortului incluzand grupul din IFIN-HH cu agentia **Fusion for Energy**.

Referintele [5,7,12,13] si [1,6,8,11] reprezinta **lucrarile in jurnale ISI**, respectiv in „*proceedings*”, realizate cu finantarea integrala la nivel national in cadrul proiectului de fata, avand inclusa in sectiunea „Acknowledgement” mentiunea acestei finantari unice la nivel national. Acestea sunt incluse si in sectiunile respective ale paginii proiectului (http://tandem.nipne.ro/~dante/projects/PN2P3_0450/index.html). Absenta unei suprapuneri cu rezultatele altor proiecte PN-II realizate de acelasi grup poate fi constata prin comparatie cu paginile acestor proiecte (<http://tandem.nipne.ro/~dante/projects.html>).

Resurse

In concordanta cu cele incluse in propunerea de proiect care a fost depusa si evaluata in competitia in urma careia a fost declarata castigatoare, a fost realizat in 23.03.2012 un anunt public¹⁶ a unei pozitii vacante (post-doc, doctorand) in cadrul echipei proiectului, pe site-ul www.euraxess.ro. In urma anunturilor mentionate mai sus au fost primite 4 aplicatii pentru pozitii anuntate ca disponibile. In final, ca urmare a aplicatiei realizata de [Dr. C. Manaiescu](#), indeplinind atat conditiile de angajare in cadrul IFIN-HH ca asistent-cercetare post-doctoral, cat si pe cele formulate in vederea angajarii in cadrul proiectului de fata, acesta a fost angajat in IFIN-HH si inclus in lista de personal a proiectului cu incepere din 17.06.2013.

Director proiect,

Marilena Avrigeanu

¹⁴ M. Avrigeanu, *Progress on the analysis of deuteron-induced reaction mechanisms at low energies*, [EFFDOC-1196](#) and [EFFDOC-1213](#), [JEFF/EFF Meetings, April/November 2013](#) (<http://www.oecd-nea.org/dbdata/jeff/effdoc.html>), OECD/NEA, Issy-les-Moulineaux, France.

¹⁵ V. Avrigeanu, *Progress on the analysis of alpha-particle optical potential at low energies*, [EFFDOC-1195](#) and [EFFDOC-1212](#), [JEFF/EFF Meeting, April/November 2013](#) (<http://www.oecd-nea.org/dbdata/jeff/effdoc.html>), OECD/NEA, Issy-les-Moulineaux, France.

¹⁶ <http://ec.europa.eu/euraxess/index.cfm/jobs/jobDetails/33772294> .