# FUNDING APPLICATION FOR
# EXPLORATORY RESEARCH PROJECTS - PN-II-ID-PCE-2011-3
## Section 3

*This document uses Times New Roman font, 12 point, 1.5 line spacing and 2 cm margins. Any modification of these parameters (excepting the figures and their captions), as well as exceeding the maximum number of pages set for each section can lead to the automatic disqualification of the application. The grey text contains instructions for the candidates and it may be removed and replaced with the required information. The black text must be kept, as it marks the mandatory information and sections of the application.*

**B. Project leader**

***B1. Scientific visibility and prestige (maximum 2 pages)***

B.1.1. *Main research results* (see also http://www.theory.nipne.ro/~poenaru)

Prediction in 1980 of cluster decay together with A. Sandulescu and W. Greiner (see http://www.britannica.com/EBchecked/topic/465998/ four years before the first experiment by Rose and Jones on $^{14}$C radioactivity of $^{223}$Ra. The following types of decays of Z=87-96 nuclei have been experimentally confirmed worldwide: $^{14}$C, $^{20}$O, $^{23}$F, $^{22,24-26}$Ne, $^{28,30}$Mg and $^{32,34}$Si. Measured half-lives are in good agreement with predictions within our analytical superasymmetric fission (ASAF) model. We investigated the field as reported in publications, invited talks at International Conferences, seminar talks abroad, books and chapters in books, etc. The ASAF model provides a unified approach of cold fission, cluster decay and $\alpha$ decay. The systematics of experimental results updated by us in 2002 was useful to stress that the strong shell effect of the daughter nucleus $^{208}$Pb was not fully exploited, so that we could suggest new measurements.

A new method to estimate the preformation probability as a penetrabilty of the internal part of the barrier within a fission theory. The simplest way to represent the systematics of half-lives for alpha-decay and heavy particle radioactivity is offered by the universal curve (UNIV).

Extention of binary fission theory to more complex phenomena like ternary fission and prediction of multicluster fission. Two-alpha accompanied fission was exp. confirmed by Goennenwein et al.

A method to determine the saddle-point shapes for binary, ternary, quaternary, and multi-cluster fission by solving an integro-differential equation derived as an Euler-Lagrange formula minimizing the deformation energy.

In 2005 we commemorated 50 years after the A. Proca's death. We disseminate informations about his relativistic equations of the massive vector boson field, and his life in Romania and in France.

Since 2007 we use the macroscopic-microscopic method to study equilibrium shapes of metallic atomic clusters. We developed a new single-particle shell model --- the hemispheroidal quantum harmonic oscillator. We explained the large yield of single ionized trimer (the analogue of an alpha particle) observed in fission experiments on doubly ionized metallic clusters.

The theory of charge collection in semiconductor detectors and the formation of current or voltage pulses at the input of associated electronics was well received by the scientific community. A book translated in english presents these results.

B.1.2. *The visibility of the scientific contributions.*

One of the most valued reviewer of **2010** named by Editors Elsevier and Nucl. Phys. A. Evaluation expert selected in **2010** by The New Eurasia Foundation for the scientific area Nuclear power and nuclear technologies. Deutsche Forschungsgemeinschaft MERCATOR Gastprofessur, Frankfurt Institute for Advanced Studies, **2009**. In **2009** the Emanuil Gojdu National College, Oradea, decided to give the name Dorin Poenaru to the Laboratory of Physics. Evaluator for the National Research Foundation of South Africa, **2007**. IFIN-HH Horia Hulubei Diploma of Honor for the outstanding contributions, **2007**. IFIN-HH Diploma of Merit for the excellent activity in **2005**. Responsible for the proposal, Negociator, and Project Coordinator of the European Union Centre of Excellence IDRANAP (InterDisciplinary Research and Aplications based on Nuclear and Atomic Physics), selected in 2000 by European Commision among the 34 succesful proposals out of 185 applications from 11 countries. **2000-2002**. Adjoint Professor, Vanderbilt University, Nashville, TN, USA, a month in **1998, 1999, 2000, 2002.** Grant of the Japan Society for the Promotion of Science to work at the Advanced Science Research Center of JAERI Tokai, **2000.** Bourse Haut Niveau granted by the Ministere de l'Enseignement Superieur et de la Recherche, Paris, **1994**. Scientific Creativity Award for prediction of cluster decay modes, Journal Flacara, Bucharest, **1988**. Romanian Academy of Science Dragomir Hurmuzescu award, for the research on fissioning isomers, **1977**. Scientific director of IFIN-HH, **1996-2000**. Member of the Scientific Council of the JINR, Dubna, Russia, **1996-1997**. Organizer and co-chairman of the International Symposium Advances in Nuclear Physics celebrating the 50-th anniversary of IFIN-HH, Bucharest, **1999.** Co-director of the NATO Advanced Study Institute on Nuclei far from Stability and Astrophysics, Predeal, **2000**. Scientific referee for Physical Review Letters, Physical Review C, Nuclear Physics A, Journal of Physics G etc. European Comission expert evaluator for FP6 and INTAS Projects. Member of the Editorial Board: International Review of PHYSICS, and Open Nuclear & Particle Physics Journal. Member of the International Advisory Committee: International Conference on Fission and Neutron-Rich Nuclei, **1999**, St Andrews; International Workshop on Biological effects of ionizing radiation, electromagnetic fields and chemical toxic agents, **2001**, Sinaia; International Conference on Applications of High Precision Atomic & Nuclear Methods, **2002**, Neptun; Third Conference on Fission and Properties of Neutron-Rich Nuclei, **2002**, Sanibel Island, USA; International Workshop on New Applications of Nuclear Fission, Bucharest, **2003**; Fourth Conference on Fission and Properties of Neutron-Rich Nuclei, **2007**, Sanibel Island, USA. One of the 7 books published abroad, Nuclear Decay Modes (IOP, Bristol, 1995), was favourably reviewed by the Nobel Prize winner K. Siegbahn and by Prof. P. Hodgson, Oxford University. Invited talks at 56 International Scientific Meetings and 30 oral contributions. 39 invited seminar talks abroad.

***Curriculum vitae*** (max. 4 pages)

B.E.E. from the Faculty of Electronics, Polytechnical Institute of Bucharest (1958). B.S. from the Faculty of Physics, University of Bucharest (1971). PhD degree in Nuclear Electronics, Polytechnical University of Bucharest (1968) and PhD degree in Theoretical Physics, Central Institute of Physics, Bucharest (1980).

1958-1962 Electronic engineer, Institute of Atomic Physics (IFA) of the Romanian Academy, Bucharest. 1962-1969 Senior electronic engineer, IFA, Bucharest. 1969-1977 Senior researcher of 3rd degree, IFA, Bucharest.

1977-1990 Senior researcher of 3rd degree, Institute of Physics and Nuclear Engineering (IFIN, former IFA reorganized). 1990-1996 Senior researcher of 1st degree, equivalent with full professor at the University. Also PhD supervisor since 1990 (IFA).

1996-2000 Scientific director of the Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH).

1996-2010 Senior researcher of 1st degree (IFIN-HH the former IFIN). PhD supervisor (Associate Professor, Faculty of Physics, University of Bucharest).

Besides the 17 articles from the period 2001-2011 written on the UEFISCSDI web site in the Section 2 (Eligibility Criteria) we select the following ***works published before 2001***:

1. D.N. Poenaru, B. Dobrescu, W. Greiner, J.H. Hamilton, A.V. Ramayya, Nuclear quasi-molecular states in ternary fission, Journal of Physics G: Nuclear and Particle Physics 26, L97-L102 (2000)

2. D.N. Poenaru, W. Greiner, J.H. Hamilton, A.V. Ramayya, E.Hourany, R.A. Gherghescu, Multicluster accompanied fission, Physical Review C 59, 3457-3460 (1999)

3. D.N. Poenaru, W. Greiner, New decay modes: multicluster spontaneous emission from nuclei, Journal of Physics G: Nuclear and Particle Physics 25, L7-L13 (1999)

4. D.N. Poenaru, W. Greiner, and R.A. Gherghescu, Shell closure at the touching point of nuclear fragments, Journal of Physics G: Nuclear and Particle Physics 24, L23-L29 (1998)

5. D.N. Poenaru, W. Greiner, R.A. Gherghescu, Energy released in ternary fission, Atomic Data and Nuclear Data Tables 68 91-147 (1998)

6. D.N. Poenaru, W. Greiner, E.Hourany, Proton-rich cluster emitter half-lives, Journal of Physics G: Nuclear and Particle Physics 22, 621-627 (1996)

7. D.N. Poenaru, W. Greiner, E. Hourany, 12-C emission from 114-Ba and nuclear properties, Physical Review, C 51, 594-600 (1995)

8. D.N. Poenaru, W. Greiner, E. Hourany, M. Hussonnois, Nuclear structure effects in cluster radioactivity, Zeitschrift fuer Physik A 349, 307-308 (1994)

9. D.N. Poenaru, W. Greiner, R.Gherghescu, New island of cluster emitters, Physical Review C 47, 2030-2037 (1993)

10. D.N. Poenaru, W. Greiner, Rare decay modes by cluster emission from nuclei, Journal of Physics G: Nuclear and Particle Physics 17, S443-S451 (1991)

11. D.N. Poenaru, W. Greiner, Cluster preformation as barrier penetrability, Physica Scripta 44 427-429 (1991)

12. D.N. Poenaru, D.Schnabel, W. Greiner, D.Mazilu, R.Gherghescu, Nuclear lifetimes for cluster radioactivities, Atomic Data and Nuclear Data Tables 48, 231-327 (1991)

13. D.N. Poenaru, W. Greiner, M.Ivascu, Predicted halflives for cluster radioactivities, Nuclear Physics, A 502, 59c-66c (1989)

14. D.N. Poenaru, J.A. Maruhn, W. Greiner, M. Ivascu, D. Mazilu, I.Ivascu, Inertia and fission paths in a wide range of mass asymmetry, Zeitschrift fuer Physik, A 333, 291-298 (1989)

15. D.N. Poenaru, J.A. Maruhn, W. Greiner, M.Ivascu, D. Mazilu, R. Gherghescu, Cold fission as heavy ion emission, Zeitschrift fuer Physik A 328, 309-314 (1987)

16. D.N. Poenaru, W. Greiner, K.Depta, M.Ivascu, D. Mazilu, A. Sandulescu, Calculated halflives and kinetic energies for spontaneous emission of heavy ions from nuclei, Atomic Data and Nuclear Data Tables 34, 423-538 (1986)

17. D.N. Poenaru, W. Greiner, M.Ivascu, D. Mazilu, I.H. Plonski, Odd-even staggering of heavy cluster spontaneous emission rates, Zeitschrift fuer Physik A 325 435-439 (1986)

18. D.N. Poenaru, W. Greiner, M. Ivascu, A. Sandulescu, Heavy cluster decay of trans-zirconium stable nuclides, Physical Review, C 32, 2198-2200 (1985)

19. A. Sandulescu, D.N. Poenaru, W. Greiner, J.H. Hamilton, Comment on exotic nuclear decay of $^{223}$Ra by emission of $^{14}$C nuclei, Physical Review Letters 54, 490 (1985)

20. D.N. Poenaru, M. Ivascu, A. Sandulescu, W. Greiner, Atomic nuclei decay modes by spontaneous emission of heavy ions, Physical Review C 32, 572-581 (1985)

21. D.N. Poenaru, M.Ivascu, A. Sandulescu, W. Greiner, Spontaneous emission of heavy clusters, Journal of Physics G: Nuclear Physics 10, L183-L189 (1984)

22. D.N. Poenaru, M. Ivascu, Estimation of the alpha-decay halflives, Journal de Physique (Paris) 44 , 791-796 (1983)

23. D.N. Poenaru, M.Ivascu, D.Mazilu, Alpha-decay halflife semiempirical relationships with self-improving parameters, Computer Physics Communications 25, 297-309 (1982)

24. D.N. Poenaru, M.Ivascu, D. Mazilu, A new semiempirical formula for the alpha decay halflives, Journal de Physique Lettres 41, L589-L590 (1980)

25. D.N. Poenaru, M.Ivascu, D.Mazilu, Folded Yukawa-plus-exponential model PES for nuclei with different charge densities, Computer Physics Communications 19, 205-214 (1980)

26. A. Sandulescu, D.N. Poenaru, W. Greiner, New type of decay of heavy nuclei intermediate between fission and alpha decay, Soviet Journal Particles and Nuclei 11 (1980) 528-541

27. D.N. Poenaru, M. Ivascu, and A. Sandulescu, Alpha-decay as a fission-like process, Journal of Physics G: Nuclear Physics 5, L169-L173 (1979)

28. D.N. Poenaru, M. Ivascu, Liquid drop models deformation energies of nuclei with axial symmetry and reflection asymmetry. Computer Physics Communications 16, 85-91 (1978)

29. D.N. Poenaru, Fission isomers. Experimental work, Ann. Phys. (Paris) 2, 133-168 (1977)

30. D.N. Poenaru, Collection time of electron-hole pairs in a coaxial Ge(Li) radiation detector, IEEE Transactions on Nuclear Science NS-14(5), 1-7 (1967)

31. D.N. Poenaru, Semiconductor radiation detectors used with current-sensitive preamplifiers associated electronics, Nuclear Instruments and Methods 54, 242-249 (1967)

32. D.N. Poenaru, Current and voltage pulses given by semiconductor radiation detectors, Nuclear Instruments and Methods 54, 229-241 (1967)

*Selected BOOKS and Chapters in Books*

33. W. Greiner, D. N. Poenaru, Cluster Radioactivity, Chapter 1, Clusters in Nuclei 1. Lecture Notes in Physics Vol. 818, (Springer, Berlin, 2010) Ed. C. Beck, pp. 1-56, ISBN 978-3-642-13898.

34. D.N. Poenaru, H. Rebel, J. Wentz (Eds), Nuclei Far from Stability and Astrophysics, Proc. of the NATO Advanced Study Institute, Predeal, August 2000. Invited talks, Series II: Mathematics, Physics and Chemistry - Vol 17, (Kluwer Academic Publishers, Dordrecht, The Netherlands, 2001) ix+427 pages.

35. D.N. Poenaru, W. Greiner (Eds), Experimental Techniques in Nuclear Physics, (Walter de Gruyter, Berlin, Germany, 1997) vi+649 pages.

36. D.N. Poenaru (Ed), Nuclear Decay Modes, xv+577 pages. (Institute of Physics Publishing, Bristol, England, 1996).

37. D.N. Poenaru, W. Greiner (Eds), Handbook of Nuclear Properties, xii+317 pages, (Clarendon Press, Oxford, England, 1996).

38. D.N. Poenaru, M. Ivascu (Eds), Particle Emission from Nuclei, vol.I Nuclear Deformation Energy, 256 pages, vol.II Alpha, Proton and Heavy Ion Radioactivities, 262 pages, vol.III Fission and Beta-Delayed Decay Modes, 247 pages, (CRC Press, Boca Raton, Florida, 1989).

39. D.N. Poenaru, N. Vilcov, Measurement of Nuclear Radiation with Semiconductor Detectors, (Chemical Publishing Company, New York, 1969) 397 pages.

40. D.N. Poenaru, Semiconductor Radiation Detector Waveforms (in Romanian), (Editura Academiei, Bucharest, 1968), 283 pages.

*Hirsch index* using citations of articles published in Journals selected on the ISI Thomson Master Journal List=**21**; by including two books, a chapter in book and the most cited theoretical paper in the field of cluster decay modes Hirsch index=**25**. Total number of citations by others: **2200**.

According to SPIRES (Stanford Linear Accelerator Center Database) we have 6 Very well-known publications (100-249 citations) and 4 well-known publications (50-99 citations). For more details see the web site: http://www.theory.nipne.ro/~poenaru, where the publications with more than 29 citations are written in green, and those with 7-29 citations in blue.

***B3. Scientific contributions from the period 2001-2011***

1. D.N. Poenaru, W. Greiner, J.H. Hamilton, A.V. Ramayya, Fragment configurations in multi-cluster fission, Journal of Physics G: Nuclear and Particle Physics, 27, L19-L28 (2001), No. of citations **C=0**, doi: 10.1088/0954-3899/27/4/101,

2. D.N. Poenaru, Y. Nagame, R.A. Gherghescu, W. Greiner, Systematics of cluster decay modes, Physical Review C 65, 054308/1-6 (2002), **C=32**, doi: 10.1103/PhysRevC.65.054308

3. D.N. Poenaru, W. Greiner, Deformation energy minima at finite mass asymmetry, EPL, 64, 164-170 (2003), **C=1**, doi: 10.1209/epl/i2003-00612-8

4. D.N. Poenaru, R.A. Gherghescu, W. Greiner, Complex fission phenomena, Nuclear Physics A, 747, 182-205 (2005), **C=4**, doi: 10.1016/j.nuclphysa.2004.09.104

5. D.N. Poenaru, I.H. Plonski, R.A. Gherghescu, W. Greiner, Valleys due to Pb and Sn on potential energy surfaces of superheavy and lighter alpha-emitting nuclei, Journal of Physics G: Nuclear and Particle Physics, 32, 1223-1239 (2006), **C=12**, doi: 10.1088/0954-3899/32/9/002

6. D.N. Poenaru, R.A. Gherghescu, W. Greiner Potential energy surfaces for cluster emitting nuclei, Physical Review C, 73, 014608 (2006), **C=4**, doi: 10.1103/PhysRevC.73.014608

7. D.N. Poenaru, I.H. Plonski, W. Greiner, Alpha-decay half-lives of superheavy nuclei, Physical Review C, 74, 014312 (2006), **C=46**, doi: 10.1103/PhysRevC.74.014312

8. D.N. Poenaru, R.A. Gherghescu, N.Carjan, Alpha-decay lifetimes semiempirical relationship including shell effects, EPL, 77, 62001 (2007), **C=1**, doi: 10.1209/0295-5075/77/62001

9. D.N. Poenaru, R.A. Gherghescu, W. Greiner, Special properties of 264Fm and of atomic clusters emitting singly charged trimers, Journal of Physics G: Nuclear and Particle Physics, 36, 125101 (2009), **C=2**, doi: 10.1088/0954-3899/36/12/125101

10. D. N. Poenaru, W. Greiner, Extension of superasymmetric fission theory from cluster decay to nanophysics, Nuclear Physics A, 834, 163c-166c (2010), **C=2**, doi: 0.1016/j.nuclphysa.2009.12.029

**C. Project description (max. 10 pages)**

C1. *Scientific context and motivation.*

Nuclear stability is a key property of atomic nuclei. In 1939, based on the macroscopic liquid drop model (LDM), Lise Meitner understood that very heavy nuclei would never exist because there would be no potential barrier against spontaneous fission. The expectations changed completely in the sixties (see Ref. [1] and the references therein). When a shell and pairing correction energy, according to the macroscopic-microscopic approach [2], is added to the LDM deformation energy, a potential barrier shows up stabilizing superheavy (SH) nuclei.

At GSI Darmstadt the elements with Z=107-112 [3] have been produced using cold fusion reactions based on closed shell nuclear targets $^{208}$Pb and $^{209}$Bi. The new isotopes $^{278}$113 and $^{277}$112 were produced at RIKEN, Japan [4] with the same cold fusion method. From 1999 to 2010 in Dubna and Lawrence Livermore Nat. Lab. the elements 113-118 have been synthesized [5] using hot fusion reactions combining targets $^{248}$Cm, $^{249}$Bk, or $^{249}$Cf with a beam of $^{48}$Ca.

Spontaneous fission --- the dominating decay mode in the region around Rf, becomes a relatively weaker branch compared to alpha-decay for the majority of recently discovered proton-rich SH nuclides, motivating an important effort to derive different methods to estimate the half-lives [6,7] and to perform systematic studies in this region e.g. [8]. Three such methods based on fission theory extended to a very large asymmetry (the analytical superasymmetric fission (ASAF) model, the universal (UNIV) curve, and the semiempirical relationship (SemFIS)) have been compared in Ref. [10].

One of the rare examples of phenomena predicted [11] before experimental discovery is heavy particle decay (HPD) or cluster radioactivity. The valleys within the PES are due to the shell effects and are clearly showing why cluster radioactivity was mostly detected in parent nuclei leading to a doubly magic lead daughter.

After the report of the first experiment in 1984 [12], the following HPD have been experimentally [13] confirmed: $^{14}$C, $^{20}$O, $^{23}$F, $^{22,24-26}$Ne, $^{28,30}$Mg, $^{32,34}$Si with half-lives in good agreement with predicted values within our ASAF model (see the review [9] and references therein). Several chapters in books and multi-authored books have been published [14]. There are many other theoretical approaches on this topic e.g., Refs. [15,16]. The ASAF model describes in a unified manner the cold fission, HPD and alpha-decay.

Besides beta decay, only alpha decay and spontaneous fission of SH nuclei have been experimentally observed up to now. We would like to take also into account HPD. Calculations are very sensitive to the released energy (Q value) obtained as a difference from the two decay products and the parent masses. Experimental masses (AME03) [17] are not available for new SH, hence we shall use calculated masses, e.g. the tables KTUY05 [18] and FRDM95 [19] with 9441 and 8979 nuclides, respectively.

The competition between these three kinds of decay modes for a large number of SH nuclei with Z=104-126 is expected to show a region where the HPD will prevail. The results of our calculations will be used to guide the future experiments aiming to produce and identify SH nuclei with Z>118.

In a systematic search for HPD we shall consider not only the emitted particles with $2<Z_e<29$ but also heavier ones up to $Z_e=Z-82$, allowing to get a doubly magic daughter around $^{208}$Pb. Our models mentioned above will be improved and used to estimate the half-lives against alpha decay, heavy particle decay, and cold fission. Potential energy surfaces showing valleys of different decay modes will be calculated within macroscopic-microcopic method with shell and BCS pairing corrections based on the two center shell model [20].

C2. *Objectives*.

The study of competition of different decay modes for a broad range of SH nuclides with atomic numbers Z=104-126 is the main objective of the project.

First indication about the possible decay modes can be obtained from potential energy surfaces (PES), were different valleys correspond to various possible decay modes, and the height of potential barrier gives a measure of stability.

A systematic search for alpha decay, heavy particle radioactivity, and cold fission in the whole nuclear chart of SH nuclides with Z=104-126 from proton drip line to neutron drip line, will allow to find the regions of parent nuclei in which one of these types of nuclear disintegrations have a chance to be the dominant mode.

The halflives against alpha decay will be calculated by using the ASAF model, the UNIV and UDL [16] universal curves, and semFIS semi-empirical formula based on fission theory.

For heavy particle radioactivities we shall employ the ASAF model, and the UNIV and UDL universal curves.

Cold fission will be investigated within ASAF model, whose results will be tested in some particular cases via least action paths of the fission dynamics.

The theoretical models will be optimized to give the lowest root mean square deviations of the half-lives for known decay modes of medium and heavy nuclei before making predictions for SH which are not produced until now. Also the results of computing the half-lives obtained by using KTUY05 and FRDM95 to calculate the released energy will be compared between each other.

. C3. *Method and approach.*

We plan to begin our project by updating the database of experimental half-lives and Q-values against charged particle decay modes to include the latest measurements for the whole chart of nuclides in four groups of even-even, even-odd, odd-even and odd-odd parents. For alpha decay we shall explore the range of atomic numbers from Z=52 to Z=118, for HPD the range Z=87-96, and for spontaneous fission the range Z=92-118. In this way we shall have 12 tables of measured values, which will be used as a reference to be compared with calculated values within every theoretical approach mentioned in the preceding section.

The free parameters of any theoretical model can be changed in order to obtain the best agreement with measureaments --- the lowest root mean square deviation. We may assume that following this optimization, our predicted half-lives for SH nuclides with Z=104-126 will be as close as possible with the real ones.

The macroscopic-microscopic method will be used to compute the potential energy surfaces (PES) of some typical nuclei versus the separation distance between fragment centers and the mass asymmetry. We have our own computer codes allowing to find the macroscopic part of deformation energy within folded Yukawa pus exponential model (Y+EM).

To this energy we add the shell and BCS pairing corrections which are calculated with Strutinsky's method using as input data the most advanced [20] single-particle two center shell model energy levels. The Fermi energy and the pairing gap will be obtained by solving numerically a system of two BCS equations.

On these PES we expect to observe clearly the valleys of spontaneous cold fission and HPD. The barrier height is the difference between the deformation energy at the saddle point and the deformation energy of the ground state minimum.

Spontaneous fission half-lives will be estimated by studying fission dynamics with nuclear inertia calculated assuming the Werner-Wheeler approximation and optimization of fission path along the least action trajectory.

From the total number of 9441 nuclides with KTUY05 masses and 8979 nuclides with FRDM95 masses we shall select only those parent nuclei, light and heavy fragments which are lying between proton and neutron drip lines. The stability against one proton, two proton, and one neutron emission will be taken as a selection criterion. For the light (emitted) fragments we can use the experimental AME03 masses.

For every parent nucleus (A,Z) selected in such a way we shall calculate a half-life spectrum versus the atomic number, $Z_e$, and mass number, $A_e$, of the emitted particle (or light fragment) taking into account all possible light fragments energetically allowed (positive Q-value). This systematic search will be made to cover alpha decay ($Z_e$=2), HPD [$Z_e$ from 3 to (Z-80)], and cold fission [$Z_e$ from (Z-80+1) to Z/2]. By using a code which automatically selects the increasing order of the life-time, we shall write in a table the Q-values and the half-lives for alpha-decay, three of the most probable HPD, and six of the most probable fission fragments.

The results obtained with different models and the two different mass tables will be compared and the regions of nuclei in which one of the three types of nuclear disintegrations have a chance to be the dominant mode will be determined.

*MILESTONES*

1. Collection of a comprehensive set of experimental data on alpha decay, heavy particle decay, and spontaneous fission in four groups of parent nuclei: even-even, even-odd, odd-even and odd-odd.

2. Using the experimental data to test and improve the accuracy of calculated half-lives against the three decay modes for different theoretical models: ASAF model, UNIV and UDL universal curves, semiempirical relationship semFIS, etc.

3. Systematic search for alpha decay, HPD, and spontaneous fission decay modes of SH nuclei with Z=104-126. The three most probable decay modes will appear clearly in the life time spectrum versus the atomic number and mass number of the emitted particle (light fragment).

4. Prediction of the regions of nuclides in which one of the three decay modes is expected to be the dominant disintegration. The table of the most probable decay modes of every parent nucleus with

Z=104-126 will show clearly for which nuclei the dominant decay mode (the lowest value of the half-life) is alpha decay, HPD or spontaneous fission.

*WORKPLAN*

The project research activities are driven by a commited group of professionals: the director, another senior researcher and a PhD student. The PhD student will work half of the time for the project because he has also other commitments related to his status of PhD student.

**Months 1-3.** Comprehensive set of experimental data on alpha decay, heavy particle decay and spontaneous fission of even-even, even-odd, odd-even and odd-odd parent nuclei.

The director and the senior researcher will work 3 man-month + 3 man-month = 6 man-month. The PhD student will work half of the time: 1.5 man-month.

**Months 4-15.** Comparison of the accuracy of the theoretical models (ASAF model, UNIV and UDL universal curves, and semFIS relationship) for nuclei with measured decay modes.

The director and the senior researcher will work 12 man-month + 12 man-month = 24 man-month. The PhD student will work half of the time: 6 man-month.

**Months 16-27.** Systematic search for alpha decay, HPD, and spontaneous fission decay modes of SH nuclei with Z=104-126.

The director and the senior researcher will work 12 man-month + 12 man-month = 24 man-month. The PhD student will work half of the time: 6 man-month.

**Months 28-36**. Regions of nuclides in which one of the three decay modes is expected to be the dominant disintegration.

The director and the senior researcher will work 9 man-month + 9 man-month = 18 man-month. The PhD student will work half of the time: 4.5 man-month.

C4. *Impact, relevance, applications*.

The experimental research activity in the field of superheavy nuclei will continue to be developed at least in the following research centres: GSI Darmstadt, Germany; JINR Dubna, Russia; RIKEN, Japan; Lawrence Livermore National Laboratory and GANIL, Caen, France. The already produced SH nuclei with Z=113-118 will be baptised by the International Union of Pure and Applied Chemistry in the near future.

The majority of the heaviest nuclides have been identified in the last decade mainly through several alpha-decay chains. The possible existence of a region of parent nuclei in which the heavy particle radioactivity will be the dominant decay mode will have important experimental and theoretical consequences. The experimental confirmation or infirmation of the project results will improve the knowledge accumulated in every theoretical model employed setting up possible limitations. Via the calculated Q-values the experiments could also test the validity of the mass calculations KTUY05 and FRDM95.

An interdisciplinary application of the macroscopic-microscopic method could be developed similarly to our approach of nanophysics of deposited atomic clusters on planar surfaces [21].

**References**

[1]. W. Greiner, D.N. Poenaru, Ch. 5 in Cluster Structure of Atomic Nuclei, Ed. M. Brenner, (Research Signpost, Trivandrum, India, 2010) p. 119.

[2]. V.M. Strutinsky, Nucl. Phys. A, 95, 420, 1967.

[3]. S. Hofmann and G. Muenzenberg, Rev. Mod. Phys., 72, 733, 2000; S. Hofmann, On Beyond Uranium (Taylor & Frances, London, 2003); Physics, 3, 31, Apr. 2010.

[4]. K. Morita et al., J. Phys. Soc. Japan, 73, 2593, 2004; 76, 043201, 2007.

[5]. Y.T. Oganessian et al., J. Phys. G: Nucl. Part. Phys., 34, R165, 2007; Phys. Rev. C, 74, 044602, 2006; Phys. Rev. Lett., 104, 142502, 2010.

[6]. G. Royer, Nucl. Phys. A, 848, 279, 2010.

[7]. A. Parkhomenko, A. Sobiczewski, Acta Phys. Polonica B, 36, 3095, 2005.

[8]. M. Gupta, T.W. Burrows, Nucl. Data Sheets, 106, 251, 2005; K.P. Santhosh, S. Sahadevan, J.G. Joseph, Nucl. Phys. A, 850, 34, 2011; D. Ni, Z. Ren, J. Phys. G, 37, 105107, 2010; D.D. Zhang, Z.Y. Ma, B.Q. Chen, S.F. Shen, Phys. Rev. C, 81, 044319, 2010; G.L. Zhang, X.Y. Le, H.Q. Zhang, Phys. Rev. C, 80, 064325, 2009.

[9]. D.N. Poenaru et al., Atomic Data Nucl. Data Tables, 48, 231, 1991.

[10] D.N. Poenaru, I.H. Plonski, R.A. Gherghescu, W. Greiner, J. Phys. G: Nucl. Part. Phys., 32, 1223, 2006; D.N. Poenaru, I.H. Plonski, W. Greiner, Phys. Rev. C, 74, 014312, 2006.

[11] A. Sandulescu, D.N. Poenaru, W. Greiner, Sov. J. Part. Nucl., 11, 528, 1980; Encyclopaedia Britannica Online, http://www.britannica.com/EBchecked/topic/465998/

[12] H.J. Rose, G.A. Jones, Nature, 307, 245, 1984.

[13] R. Bonetti, A. Guglielmetti, Rom. Rep. Phys., 59, 301, 2007.

[14] D.N. Poenaru, W. Greiner, Eds., Handbook of Nuclear Properties (Clarendon Press, Oxford, 1996); D.N. Poenaru, Ed., Nuclear Decay Modes (IOP Publishing, Bristol, 1996).

[15] D. Ni, Z. Ren, Phys. Rev. C, 82, 024311, 2010; K.P. Santhosh, R.K. Biju, S. Sahadevan, Nucl. Phys. A, 838, 38, 2010; B.B. Singh, S.K. Patra, R.K. Gupta, Phys. Rev. C, 82, 014607, 2010.

[16] C. Qi, F.R. Xu, R.J. Liotta, R. Wyss, Phys. Rev. Lett., 103, 072501, 2009; D.S. Delion,Phys. Rev. C, 80, 024310, 2009; J.M. Dong, H.F. Zhang, J.Q. Li, W. Scheid, Europ. Phys. J. A, 41, 197, 2009; S. Kumar, R. Rani, R. Kumar, J. Phys. G: Nucl. Part. Phys., 36, 015110, 2009; D. Ni, Z. Ren, T. Dong, C. Xu, Phys. Rev. C, 78, 044310, 2008.

[17] G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A, 729, 337, 2003.

[18] H. Koura, T. Tachibana, M. Uno, M. Yamada, Prog. Theor. Phys., 113, 305, 2005.

[19] P. Moeller, J. R. Nix, W. D. Myers, and W. J. Swiatecki, Atomic Data Nucl. Data Tables, 59, 185, 1995.

[20] R.A. Gherghescu, Phys. Rev. C, 67, 014309, 2003.

[21] D.N. Poenaru, R.A. Gherghescu, A.V. Solov'yov, W. Greiner, EPL, 79, 63001, 2007; 88, 23002, 2009; Europ. Phys. J. D, 47, 379, 2008; Phys. Lett. A, 372, 5448, 2008; D.N. Poenaru, R.A. Gherghescu, W. Greiner, J. Phys. G, 36, 125101, 2009; 37, 085101, 2010; D.N. Poenaru, W. Greiner, Nucl. Phys. A, 834, 163c, 2010.

C5. *Resources and budget*.

The exisiting infrastructure in our Department (Desktops, Laptops, Printers, Scanners, Photo Copiers, etc) makes possible a good development of the theoretical research activity for all members of our team. Essentially we use fast computers in order to reduce the long running times to diagonalize a large matrix in order to obtain the asymmetric two center shell model nuclear levels.

The traditional international cooperation with Frankfurt Institute of Advance Studies help us very much to achieve the goals of the project. Consequently we shall spend some money for the mobility. A part of the mobility budget will be also used to cover the expenses of participating at International Conferences, Symposia, Workshops and Summer Schools.

**Budget Breakdown (lei)**

| **Budget chapter (expenses)** | **2011 (lei)** | **2012 (lei)** | **2013 (lei)** | **2014 (lei)** | **Total (lei)** |
|---|---|---|---|---|---|
| **Salaries** | 83333 | 310333 | 310333 | 227001 | **931000** |
| **Inventory** | | | | | |
| **Mobility** | | 23000 | 23000 | 23000 | **69000** |
| **Overhead** | 41666 | 166667 | 166667 | 125000 | **500000** |
| **Total** | **125000** | **500000** | **500000** | **375000** | **1500000** |

**Budget Breakdown (euro)**

| **Budget chapter (expenses)** | **Total (euro)** |
|---|---|
| **Salaries** | 216511,63 |
| **Inventory** | |
| **Mobility** | 16046,51 |
| **Overhead** | 116279,07 |
| **Total** | **348837,21** |

With excange rate 1 EUR = 4,3 LEI

We received from our Institute the following justification of the large overhead of 50% of the direct costs, also uploaded as a file 'OverheadJustificationIFINHH.pdf' on the web site of the Project.

National Research Institute for Physics and Nuclear Engineering "Horia Hulubei" is the largest national institute in Romania in all aspects, including assets and infrastructure. Funding the administrative activities of the institute is made only by overheads applied to research projects. Overheads are those expenses not directly attributable to a project and must be distributed based on distribution keys. Those distribution keys, as required by law, shall be determined by each institution in accordance with the accounting policies applied under the Order 3055/2009.

The indirect costs are: administrative staff salaries (about 11% of the direct costs); paid leave (vacations) for the staff involved in the project (about 13% of the direct costs); depreciation of equipment (about 11% of direct costs); fees and taxes (other than those for salaries) (about 5% of the direct costs); utilities (about 5% of direct costs), and others (materials, repairs, bank fees, insurances, etc) (about 5% of direct costs).

If these costs are not covered, a series of institute’s expenses will remain uncovered with negative financial implications for the financial results of the institute. In this case the institute will have accounting losses and becomes ineligible to participate in future competitions organized within the national and international research programs.

Under these circumstances the projects implemented by the institute must use an overhead coefficient of 50% from direct costs.

**The information in this application is hereby certified to be correct.**

Project leader,
Last name, first name: POENARU, Dorin N.

Signature:
Date: 28.04.2011