# PRE-PROPOSAL COVER PAGE

Title of proposed project: *Development of long pulse PMI solutions*, in response to LAB 12-714 and DE-FOA 12-714: "Collaborative Research in Magnetic Fusion Energy Sciences on International Research Facilities"

Name of laboratory: Oak Ridge National Laboratory
Name of principal investigator (PI): Rajesh Maingi, co-PI: Jeff Harris
Position title of PI: Distinguished R & D Staff Member
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Institutional PI: X. Xu, Lawrence Livermore National Laboratory
Institutional PI: T. Petrie, General Atomics
Institutional PI: A. Pankin, Tech-X Corp.
Institutional PI: J. Brooks, Purdue University
Institutional PI: N. Morley, University of California at Los Angeles
Institutional PI: A. Pigarov, University of California at San Diego
Institutional PI: D. Ruzic, University of Illinois at Urbana-Champaign
Additional Senior Researchers: J.P. Allain (Purdue), D. Andruczyk (UIUC), J. Harris (ORNL), A. Hassanein (Purdue), M. Jaworski (PPPL), R. Kaita (PPPL), B.E. Koel (Princeton U.), S. Krasheninnikov (UCSD), T. Rognlien (LLNL), C. Skinner (PPPL), D. Stotler (PPPL), A. Ying (UCLA)

Requested funding for each year; total request:
FY2013-15: $3.0M each year; $9.0M total

Use of human subjects in proposed project: No
Use of vertebrate animals in proposed project: No

Signature of PI, date of signature

Rajesh Maingi 11-MAY-2012

**Pre-Proposal for International Collaborations Solicitation**

*Development of Long Pulse PMI Solutions*

The purpose of this pre-proposal is to extend and develop solutions to the plasma-material interface (PMI) that could be utilized for long pulse discharges, e.g. as envisioned in ITER and/or a Fusion Nuclear Science Facility. Specifically, this pre-proposal targets topical area #3 (Plasma-Wall interactions) in response to DOE Program Announcements LAB 12-714 and DE-FOA 12-714: "Collaborative Research in Magnetic Fusion Energy Sciences on International Research Facilities".

The proposal will consist of two main elements: the physics design of a long pulse, shaped tungsten divertor and pump plenum for the KSTAR device, and the evaluation of liquid lithium as a plasma facing component (PFC) for long pulse discharges in the EAST device. Each of these is described in the paragraphs below. The two facilities are complementary in that KSTAR is focused on high-Z PFCs, while EAST has invested substantial resources in investigating lithium coatings, previously on a carbon wall and now with Molybdenum PFCs. In addition, the proposal is being developed by the following institutional teams: Oak Ridge National Laboratory (ORNL), Princeton Plasma Physics Laboratory (PPPL) and Princeton University (PU), Lawrence Livermore National Laboratory (LLNL), General Atomics (GA), Purdue University (PU), Tech-X Corp. (TXC), University of California at Los Angeles (UCLA), University of California at San Diego (UCSD), and the University of Illinois at Urbana-Champaign (UIUC).

The KSTAR management team has identified the need for a high-Z, shaped divertor and associated cryopump plenum to handle the particle and power exhaust in long pulse discharges with high auxiliary heating power, and they have asked for the U.S. to take a central role in the physics design of the divertor system, followed by a significant role in collaborative experiments following implementation. Such an arrangement has obvious benefits to the U.S. and its preparation for participation in ITER as well as design of a divertor for a Fusion Nuclear Science Facility. Specifically, our team will participate in experiments (ORNL, GA) that benchmark the edge cross-field transport rates in 2-D plasma and neutrals interpretive models like SOLPS (ORNL) and UEDGE (LLNL, UCSD) with the existing divertor. Those cross-field transport rates will be used to predict the change in divertor performance and evaluate cryopump efficiency with tungsten PFCs and with divertor shaping, e.g. the use of vertical targets to facilitate detachment, the use of domes and W-shaped slots to reduce the impact of the private flux region and the connection between inner and outer strike zones. In addition, we will use modeling with BOUT++ to predict changes to the edge turbulent transport with the proposed divertor changes (LLNL). Finally we will evaluate the evolution of the wall recycling state with evolving wall temperature and surface concentration with the WALLPSI code (UCSD). The FACETS framework will be used to couple WALLPSI with UEDGE and SOLPS (TXC). The resulting, optimized physics design will be used as the basis for an engineering design that will be led by the KSTAR team, from which the time table for obtaining the resources needed for deployment will be determined. Two additional

experimental tasks include development of highly instrumented, densely packed tiles, including e.g. fast thermocouples, Langmuir probes, magnetic probes, sample coupons, and local $D_\alpha$ measurements, etc., as well as lower hybrid heating and divertor interactions (ORNL).

The main focus of proposed activities in EAST is to evaluate the potential of liquid lithium as a long pulse PFC, building on the lithium coating studies in EAST and NSTX, as well as the short-pulse liquid lithium divertor studies in NSTX. EAST is presently considering implementation of a mid-plane movable liquid lithium limiter to assess lithium PFC performance in a long-pulse tokamak environment. Because lithium is so chemically active, an important correlated study is material migration (e.g. hydrogenated lithium compounds) associated with lithium coatings, which must be confronted for lithium to be considered in future devices. The following tasks are envisioned:

1) We will propose to develop the technology of liquid metal handling and PFCs to provide designs and guidance to the EAST team, for eventual testing in EAST. The main focus will be on gaseous cooling systems for the lithium limiter and possible future divertor applications, infrastructure supporting these limiter concepts such as liquid metal circulating loops, and actively-cooled capillary-restrained systems, as well as the Lithium-Metal Infused Trenches (LiMIT) concept. Improved methods for lithium granule formation will also be pursued to potentially enable continuous lithium coating delivery. (PPPL, UIUC)
2) We will propose to model the transient effects on liquid Li behavior, as well as free-surface MHD modeling of stationary and transient performance of free-surface liquid metal PFC concepts that are to be tested on the EAST lithium limiter. (UCLA, Purdue)
3) Collaborative experiments on the Magnum-PSI linear test stand at DIFFER (formerly FOM) in the Netherlands would be carried out to generate fundamental surface-interaction data in a divertor-relevant plasma. Experiments would be conducted on C, W, Mo substrates (all expected in EAST), with and without lithium coatings. Studies of the surface chemistry and morphology of these materials will be performed using extensive, existing surface analysis equipment. Experiments would then be conducted on EAST to study coating lifetime, erosion, redeposition and migration, and these would be modeled with erosion/redeposition calculations. Plasmas and associated transport will be modeled with available tools (e.g. WBC-Redep and OEDGE/DIVIMP code suite), and mixed material effects would also be modeled. (PPPL, Princeton, Purdue)
4) Experiments on university-based test stands would be carried out to complement Magnum-PSI plasma data and interpretation. (UIUC, Princeton, Purdue)

## Dr. Rajesh Maingi Biographical Sketch

Education and training:

Ph.D, Dept. of Nuclear Engineering, N.C. State University, 1992
Thesis title: "Coupled 2-D Edge Plasma and Neutral Gas Simulations of Tokamak Scrape-off Layers"
B.S. Dept. of Nuclear Engineering, N.C. State University, 1987

Research and Professional Experience:

2011: Obtained Joint Faculty Appointment, Rank of Professor, UT-Knoxville, Dept. of Nucl. Engineering
1997-present: staff member, Oak Ridge National Lab; present title: Distinguished R & D Staff
1992-1997: postdoctoral research associate, ORNL on-site at General Atomics at the DIII-D facility

Relevant recent publication list:


1. R. Maingi, M.G. Bell, R.E. Bell, C.E. Bush, E.D. Fredrickson, D.A. Gates, S.M. Kaye, H.W. Kugel, B.P. LeBlanc, J.E. Menard, D. Mueller, S.A. Sabbagh, D. Stutman, G. Taylor, D.W. Johnson, R. Kaita, R.J. Maqueda, M. Ono, F. Paoletti, Y-K.M. Peng, A.L. Roquemore, C.H. Skinner, V.A. Soukhanovskii, and E.J. Synakowski, "Characteristics of the First H-mode Discharges in the National Spherical Torus Experiment', *Phys. Rev. Lett*. **88** (2002) 035003.
2. R. Maingi, H.W. Kugel, C.J. Lasnier, A.L. Roquemore, V.A. Soukhanovskii, C.E. Bush, and the NSTX Team, "Heat Flux Scaling Experiments in NSTX", *J. Nucl. Mater*. **313-316** (2003) 1005.
3. R. Maingi, M.G. Bell, R.E. Bell, C.E. Bush, E.D. Fredrickson, D.A. Gates, T. Gray, D.W. Johnson, R. Kaita, S.M. Kaye, S. Kubota, H.W. Kugel, C.J. Lasnier, B.P. LeBlanc, R.J. Maqueda, D. Mastrovito, J.E. Menard, D. Mueller, M. Ono, F. Paoletti, S.J. Paul, Y.-K.M. Peng, A.L. Roquemore, S.A. Sabbagh, C.H. Skinner, V.A. Soukhanovskii, D. Stutman, D.W. Swain, E.J. Synakowski, T. Tan, J.B. Wilgen and S.J. Zweben, "H-mode Research in NSTX", *Nucl. Fusion* **43** (2003) 969.
4. R. Maingi, C.E. Bush, E.D. Fredrickson, D.A. Gates, S.M. Kaye, B.P. LeBlanc, J.E. Menard, H. Meyer, D. Mueller, N. Nishino, A.L. Roquemore, S.A. Sabbagh, K. Tritz, S.J. Zweben, M.G. Bell, R.E. Bell, T. Biewer, J.A. Boedo, D.W. Johnson, R. Kaita, H.W. Kugel, R.J. Maqueda, T. Munsat, R. Raman, V.A. Soukhanovskii, T. Stevenson and D. Stutman, "H-mode Pedestal, ELM, and Power Threshold Studies in NSTX", *Nucl. Fusion* **45** (2005) 1066.
5. R. Maingi, C.E. Bush, R. Kaita, H.W. Kugel, A.L. Roquemore, S.F. Paul, V.A. Soukhanovskii, and the NSTX team, "Divertor Heat Flux Scaling with Heating Power and Plasma Current in H-mode Discharges in the National Spherical Torus Experiment", *J. Nucl. Mater.* **363-365** (2007) 196.
6. R. Maingi, T.H. Osborne, B.P. LeBlanc, R.E. Bell, J. Manickam, P.B. Snyder, J.E. Menard, D.K. Mansfield, H.W. Kugel, R. Kaita, S.P. Gerhardt, S.A. Sabbagh, F.A. Kelly, and the NSTX research team, "ELM suppression through density profile modification with lithium wall coatings in the NSTX", *Phys. Rev. Lett.* **103** (2009) 075001.
7. R. Maingi, S.M. Kaye, and the NSTX team, "Overview of L-H power threshold studies in NSTX", *Nucl. Fusion* **50** (2010) 064010.
8. R. Maingi, R.E. Bell, J.M. Canik, S.P. Gerhardt, S.M. Kaye, B.P. LeBlanc, T.H. Osborne, M.G. Bell, E.D. Fredrickson, K.C. Lee, J.E. Menard, J.-K. Park, S.A. Sabbagh, and the NSTX team, "Triggered confinement enhancement and pedestal expansion in high confinement mode discharges in the NSTX", *Phys. Rev. Lett.* **105** (2010) 135004.
9. R. Maingi, A.E. Hubbard, H. Meyer, J.W. Hughes, A. Kirk, R. Maqueda, J.L. Terry and the Alcator C-Mod, MAST, and NSTX teams, "Comparison of Small ELM Characteristics and Regimes in Alcator C-mod, MAST, and NSTX", *Nucl. Fusion* **51** (2011) 063036.
10. R. Maingi, S.M. Kaye, C.H. Skinner, D.P. Boyle, J.M. Canik, M.G. Bell, R.E. Bell, T.K. Gray, M.A. Jaworski, R. Kaita, H.W. Kugel, B.P. LeBlanc, D.K. Mansfield, T.H. Osborne, S.A. Sabbagh, and V.A. Soukhanovskii, "The continuous improvement of H-mode discharge performance with progressively increasing lithium coatings in NSTX", *Phys. Rev. Lett.* **107** (2011) 145004.

Synergistic Activities

1. Dr. Maingi conducts boundary physics research on NSTX through an ORNL contract, presently serving as co-leader of the ITER and Cross-Cutting/Enabling Topical Science Group
2. Dr. Maingi serves as deputy international leader of US participation in the International Tokamak Physics Activity (ITPA) pedestal physics working group
3. Dr. Maingi serves on the Executive Committee of the Division of Plasma Physics of the APS
4. Dr. Maingi serves on the Executive Committee of the U.S. Transport Task Force
5. Dr. Maingi serves on the Edge Coordinating Committee

| Collab. Institution | Collaborator Names |
|---|---|
| Columbia U. | S. Sabbagh |
| General Atomics | N. Brooks, T. Evans, P. Gohil, R. Groebner, T. Osborne, P. Snyder |
| IPP-Greifswald | Y. Feng |
| JAEA Japan | K. Kamiya, N. Oyama |
| Johns Hopkins U. | L. Delgado-Aparicio, D. Stutman, K. Tritz |
| Tech-X | A. Pankin |
| LLNL | M. Fenstermacher, D. Hill, C. Lasnier, V. Soukhanovskii, X. Xu |
| Lodestar | D. D'Ippolito, J. Myra |
| MIT | A. Hubbard, J. Hughes, B. LaBombard, B. Lipshultz, J. Terry, D. Whyte |
| Nova Photonics | F. Levinton, H. Yuh |
| ORISE/ORNL | T.K. Gray, A. McLean, M. Shafer |
| ORNL | J-W. Ahn, T. Biewer, C. Bush, J. Canik, E. Unterberg, J. Lyon, A. Sontag |
| PPPL | D. Battaglia, M. Bell, R. Bell, C.S. Chang, E. Fredrickson, D. Gates, S. Gerhardt, R. Goldston, R. Hawyrluk, J. Hosea, D. Johnson, R. Kaita, S. Kaye, H. Kugel, B. LeBlanc, D. Lundberg, R. Majeski, J. Manickam, D. Mansfield, J. Menard, D. Monticello, D. Mueller, H. Park, J-K. Park, M. Ono, S. Paul, L. Roquemore, C. Skinner, T. Stevenson, D. Stotler, G. Taylor, M. Zarnstorff, S. Zweben |
| Princeton U. | D. Boyle, J. Rhoads, J. Surany |
| Purdue U. | J.P. Allain, J. Brooks, A. Hassanein |
| SWIP China | L. Yan |
| Unaffiliated | F. Kelly, R. Maqueda |
| UC-Irvine | C. Domier, M. Johnson, K.C. Lee, N.C. Luhmann |
| UCSD | J. Boedo, T.K. Mau, S. Mordijck |
| UCLA | S. Kubota |
| UT-Austin | M. Kotschenreuther, S. Mahajan, P. Valanju |
| UT-Knoxville | B. Wirth |
| U. Washington | R. Raman |
| UKAEA-Culham | B. Lloyd, A. Kirk, H. Meyer, S. Saarelma, R. Scannell |

Graduate and Postdoctoral advisors and Advisees:

NC State U. J. Gilligan, O. Hankins (Ph.D. thesis advisors)

Retired P. Mioduszewski (Postdoctoral fellowship advisor)

**Dr. Jeffrey H. Harris Biographical Sketch**

Education and training:
Ph.D, Dept. of Electrical Engineering, University of Wisconsin-Madison, 1981
Thesis: "Low-Frequency Coherent Fluctuations in the Proto-Cleo Torsatron"
M.S.,Dept. of Electrical Engineering, Massachusetts Institute of Technology, 1976
Thesis: "Interferometric Studies of Anode Spot Formation in High-Current Vacuum Arcs"
B.S., Dept. of Electrical Engineering, Massachusetts Institute of Technology, 1973

Research and Professional Experience:
2005-present:
Oak Ridge National Laboratory
Distinguished Research Staff
1997-2005
Australian National University
Professor
Head, Plasma Research Laboratory, Australian National University
Director, Australian National Fusion Plasma Research Facility.
1981-1997
Oak Ridge National Laboratory
Research Staff and Senior Research Staff

Project assignments:
L-2 Stellarator, General Physics Institute, Moscow, Russia, 1977
Advanced Toroidal Facility (ATF), ORNL, 1981-1992
Heliotron-E stellarator, Kyoto University, Japan, 1983
Design of TJ-1.5 and TJ-II stellarators, ORNL and CIEMAT-Spain, 1985
Tore Supra tokamak, CEA-Cadarache, France, 1993-1997
Deputy Project Manager, National Compact Stellarator Experiment, 2008
Co-Principal Investigator, US W7X collaboration, 2010-present

Relevant publication list:

1. J. H. Harris, "Electron Density Measurements in Vacuum Arcs at Anode Spot Formation Threshold," J. Appl. Phys. **50**, 753 (1979).
2. C. Hidalgo, J. H. Harris, T. Uckan, J. D. Bell, B. A. Carreras, J. L. Dunlap, G. R. Dyer, C. P. Ritz, A. J. Wootton, M. A. Meier, T. L. Rhodes and K. Carter, "Plasma Fluctuations Near the Shear Layer in the ATF Torsatron," Nucl. Fusion **31**, 1471 (1991).
3. J. H. Harris, L. A. Charlton, G. L. Bell, J. D. Bell, T. S. Bigelow, B. A. Carreras, R. J. Colchin, N. A. Crocker, J. E. C. Crume, N. Dominguez, J. L. Dunlap, G. R. Dyer, A. C. England, J. C. Glowienka, G. R. Hanson, D. L. Hillis, S. Hiroe, L. D. Horton, H. C. Howe, R. C. Isler, T. C. Jernigan, J. N. Leboeuf, D. K. Lee, V. E. Lynch, J. F. Lyon, M. M. Menon, M. Murakami, D. A. Rasmussen, C. P. Ritz, C. E. Thomas, T. Uckan, M. R. Wade, J. B. Wilgen, W. R. Wing, E. Anabitarte, B. Brañas, C. Hidalgo and J. Sanchez, "Fluctuations and Stability in the ATF Torsatron," in *Plasma Physics and Controlled Nuclear Fusion Research* (IAEA, Vienna, 1991), Vol. 2, p. 677.
4. C. E. Thomas, J. H. Harris, G. R. Haste, C. C. Klepper, J. Hogan, S. J. Tobin, F. W. Baity, M. D. Carter, D. J. Hoffman, P. H. Ryan, B. Saoutic, B. Beaumont, A. Becoulet, H. Kuus, D. Fraboulet, A. Grosman, D. Guilhem, J. Walter, T. Loarer, M. Chatelier and Équipe TORE SUPRA, "First Measurements of ICRF and Edge/SOL Plasma Interactions on TORE SUPRA," J. Nucl. Mat. **220-222,** 531(1995).

5. J. H. Harris, T. Hutter, J. T. Hogan, V. Basiuk , B . Beaumont , A. Becoulet , S. Bremond , M. D. Carter , M. Goniche , R. H. Goulding , D. Guilhem , G. R. Haste , D. J. Hoffman , H. Kuus , L. Ladurelle , X. Litaudon , and F. Nguyen, "Plasma-surface Interactions with ICRF Antennas and Lower Hybrid Grills in TORE SUPRA," J. Nucl. Mat. **241-243**, 511 (1997).
6. J. Mailloux, Y. Demers, V. Fuchs, P. Jacquet, C. Boucher, A. Côté, C. Côté, J. Gunn, B. Tetreault, M. Goniche, P. Bibet, P. Froissard, D. Guilhem, J. H. Harris, G. Rey, and M. Tareb, "Strong Toroidal Aysmmetries in Power Deposition on Divertor and First-Wall Components during LHCD on TdeV and TORE SUPRA," J. Nucl. Mat. **241-243**, 745 (1997).
7. M. Goniche, D. Guilhem, P. Bibet,, P. Froissard, X. Litaudon, G. Rey, J. Maillouz, Y. Demers, V. Fuchs, P. Jacquet, J. H. Harris, J. T. Hogan, "Enhanced Heat Flux in the Scrape-off Layer due to Electrons Accelerated in the Near Field of Lower Hybrid Grills," Nucl. Fusion 38, 919 (1998).
8. C. Charles, A. W. Degeling, T. E. Sheridan, J. H. Harris, M. A. Lieberman, and R. W. Boswell, "Absolute measurements and modeling of radio frequency electric fields using a retarding field energy analyzer," Physics of Plasmas **12**, 5232 (2000).
9. S.T.A. Kumar B.D. Blackwell, J. Howard and J.H. Harris, "Spontaneous transition of core radial electric field driven by magnetic islands in the H-1NF heliac," Nucl. Fusion **51**, 083003 (2011).

Other Professional Activities
Stellarator Executive Committee, International Energy Agency, 1997-present
Consultant, Parliament of Australia, 2002
US Dept of Energy. FESAC. Greenwald Fusion Panel, 2007
International Tokamak Physics Activity (ITPA)-Stability, 2008-present
Associate Editor, Physical Review Letters, 2008-2010
US Dept of Energy. FESAC. Int'l Collaboration Committee, 2012

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| Australian Nat'l Univ. | B. Blackwell, R. Dewar, J. Howard, M. Shats, G. G. Borg |
| CEA-Cadarache | A. Becoulet, T. Hoang, X. Litaudon, B. Saoutic, D. Guilhem, T. Hutter, M. Goniche, L. Colas |
| CIEMAT | J. Sanchez, E. Ascascibar, C. Hidalgo, K. McCarthy |
| Columbia Univ. | A. Boozer |
| General Atomics | T. Evans, A. D. Turnbull |
| IPP-Greifswald | A. Dinklage, T. Klinger |
| IPP-Garching | A. Peacock |
| NIFS | H. Yamada, S. Okamura, S. Ohdachi |
| ORISE/ORNL | M. Shafer |
| ORNL | J-W. Ahn, T. Biewer, J. Canik, E. A. Unterberg, J. Lyon, A. Sontag, J. D. Lore, C. C. Klepper, P. Krstic, E. A. Lazarus, N. Commaux, L. Baylor |
| PPPL | D. Gates, G. H.Neilson, A. Reiman, S. Lazerson, M. Zarnstorff |
| UCSD | D. Rudakov, R. A. Moyer |
| Univ. of Wisconsin | D. T. Anderson, J. N. Talmadge, K. Likin, C. Hegna, S. T. A. Kumar |

Graduate and Postdoctoral advisors and advisees:

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|---|---|
| Univ. of Wisconsin | J. L. Shohet (Ph.D. thesis advisor) |
| Australian Nat'l Univ. | D. Rudakov, W. Solomon, S. T. A. Kumar, F. Glass (advisees) |

## Dr. Jonathan Menard Biographical Sketch

Education and training:
Ph.D., Dept. of Astrophysical Sciences, Princeton University, 1998
Thesis title: "High-Harmonic Fast Wave Coupling and Heating Experiments in the CDX-U Spherical Tokamak"
B.S. Dept. of Nuclear Engineering and Engineering Physics, University of Wisconsin, Madison, WI, 1992

Research and Professional Experience:
2007-present: Program Director for National Spherical Torus eXperiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL)
1999-present: staff member, PPPL; present title: Principal Research Physicist
1998-1999: postdoctoral research associate, PPPL on CDX-U and NSTX

Selected relevant publication list:


1. J.E. Menard, S. Gerhardt, M. Bell, J. Bialek, A. Brooks, J. Canik, J. Chrzanowski, M. Denault, L. Dudek, D. A. Gates, N. Gorelenkov, W. Guttenfelder, R. Hatcher, J. Hosea, R. Kaita, S. Kaye, C. Kessel, E. Kolemen, H. Kugel, R. Maingi, M. Mardenfeld, D. Mueller, B. Nelson, C. Neumeyer, M. Ono, E. Perry, R. Ramakrishnan, R. Raman, Y. Ren, S. Sabbagh, M. Smith, V. Soukhanovskii, T. Stevenson, R. Strykowsky, D. Stutman, G. Taylor, P. Titus, K. Tresemer, K. Tritz, M. Viola, M. Williams, R. Woolley, H. Yuh, H. Zhang, Y. Zhai, A. Zolfaghari, and the NSTX Team, "Overview of the Physics and Engineering Design of NSTX Upgrade", submitted to Nuclear Fusion, Fall 2011.
2. L Berzak Hopkins, J Menard, R Majeski, D P Lundberg, E Granstedt, C Jacobson, R Kaita, T Kozub, and L Zakharov, "Plasma equilibrium reconstructions in the lithium tokamak experiment", submitted to Nuclear Fusion, Fall 2011.
3. J.E. Menard, L. Bromberg, T. Brown, T. Burgess, D. Dix, L. El-Guebaly, T. Gerrity, R.J. Goldston, R.J. Hawryluk, R. Kastner, C. Kessel, S. Malang, J. Minervini, G.H. Neilson, C.L. Neumeyer, S. Prager, M. Sawan, J. Sheffield, A. Sternlieb, L. Waganer, D. Whyte and M. Zarnstorff, "Prospects for pilot plants based on the tokamak, spherical tokamak, and stellarator" Nuclear Fusion 51 (August 2011) 103014
4. J.E. Menard, R.E. Bell, D.A. Gates, S.P. Gerhardt, J.-K. Park, S.A. Sabbagh, J.W. Berkery, A. Egan, J. Kallman, S.M. Kaye, B. LeBlanc, Y.Q. Liu, A. Sontag, D. Swanson, H. Yuh, W. Zhu, NSTX Research Team "Progress in understanding error-field physics in NSTX spherical torus plasmas" Nuclear Fusion 50, (March 2010) 045008
5. J.E. Menard, R.J. Goldston, G.-Y. Fu, N. Gorelenkov, S.M. Kaye, G. Kramer, R. Maingi, C.L. Neumeyer, S.A. Sabbagh, V.A. Soukhanovskii, R. Woolley, "Physics Design of the National High-power Advanced Torus eXperiment" 34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.31F, P-1.162 (2007)
6. J. E. Menard, R. E. Bell, D. A. Gates, S. M. Kaye, B. P. LeBlanc, F. M. Levinton, S. S. Medley, S. A. Sabbagh, D. Stutman, K. Tritz, and H. Yuh, "Observation of Instability-Induced Current Redistribution in a Spherical-Torus Plasma" Physical Review Letters 97, 095002 (2006)
7. J.E. Menard, M.G. Bell, R.E. Bell, E.D. Fredrickson, D.A. Gates, S.M. Kaye, B.P. LeBlanc, R. Maingi, D. Mueller, S.A. Sabbagh, D. Stutman, C.E. Bush, D.W. Johnson, R. Kaita, H.W. Kugel, R.J. Maqueda, F. Paoletti, S.F Paul, M. Ono, Y.-K.M. Peng, C.H. Skinner, E.J. Synakowski and the NSTX Research Team, "Beta-limiting MHD instabilities in improved-performance NSTX spherical torus plasmas" Nuclear Fusion 43, (2003) 330-340

8. J. Menard, R. Majeski, R. Kaita, M. Ono, and T. Munsat, D. Stutman and M. Finkenthal, "High-harmonic fast magnetosonic wave coupling, propagation, and heating in a spherical torus plasma", Phys. Plasmas, Vol. 6, No. 5, (1999) 2002


Synergistic Activities

1. Dr. Menard leads the physics research program for the National Spherical Torus eXperiment (NSTX), including defining the near-term and long-term goals and research and development programs for solid and liquid lithium PFC research in NSTX (past) and NSTX Upgrade (present and future).
2. Dr Menard is also serving as leader of the ITER and Cross-Cutting/Enabling Topical Science Group on NSTX with emphasis on developing and understanding sustained particle control with lithium and cryo-pumps.
3. Dr. Menard presently serves on the KSTAR Program Advisory Committee (PAC), and also the MAST PAC
4. Dr. Menard has extensive experience in MHD stability and scenario optimization, and served as MHD topical group leader in U.S. Burning Plasma Organization (2006-2008), PPPL science focus group leader for Macroscopic Stability (2005-2007), was the U.S. member of ITPA MHD topical group representing NSTX (2005-2009), served as the Experimental Run Coordinator for NSTX (2005), served several terms as NSTX Experimental Task Group Leader for MHD and/or Integrated Scenarios, was responsible for all magnetic diagnostics on NSTX (1999-2007).
5. Dr. Menard has a broad background in plasma and toroidal confinement physics, and program planning, and served as a committee member on ''Plasma 2010: An Assessment of and Outlook for Plasma Science'', published by the National Research Council of the National Academies (Sept. 2005-May 2007), was a member of the National Compact Stellarator PAC (2002-2008), and a member of the DIII-D PAC (2002-2004).

| Collab. Institution | Collaborator Names |
|---|---|
| ASIPP/EAST | J. Li, B. Wan, H. Guo, J.S. Hu |
| Columbia University | S. Sabbagh, J. Berkery, J. Bialek, M. Mauel |
| General Atomics | T. Strait, R. Buttery, T. Luce, A. Garofalo |
| IPP-Garching | V. Igochine |
| JAEA Japan | Y. Kamada, N. Asakura |
| Johns Hopkins U. | D. Stutman, K. Tritz, D. Clayton |
| Kurchatov Inst. | B. Kuteev |
| LLNL | V. Soukhanovskii, D. Ryutov, E. Meier |
| MIT | B. Lipschultz, D. Whyte |
| Nova Photonics | F. Levinton, H. Yuh, J. Foley |
| NFRI | Y-K Oh |
| ORNL | J. Canik, M. Peng, A. Lumsdaine, T.K. Gray |
| PPPL | Pretty much any member of the PPPL experimental research staff |
| Princeton U. | B. Koel, C. Rowley |
| Purdue U. | J.P. Allain, J. Brooks |
| Seoul National Univ. | Y-S Hwang |
| St-Petersburg (Russia) | A. Bykov, V. Sergeev |
| Tech-X | S. Kruger |
| UCLA | T. Carter, N. Crocker, S. Kubota |
| UT-Austin | M. Kotschenreuther, S. Mahajan, P. Valanju |
| U. Rochester | R. Betti |
| U. Tulsa | D. Brennan |
| U. Wisconsin | R. Fonck |
| U. Washington | R. Raman, B. Nelson |
| UKAEA-Culham | B. Lloyd, H. Meyer, G. Voss, Y. Liu |
| York University | H. Wilson |
| X Science, LLC | R. Maqueda |

Graduate and Postdoctoral advisors and Advisees:

| | |
|---|---|
| Princeton University | M. Ono, S. Jardin (Ph.D. thesis advisors) |
| PPPL | J. Hosea and the PPPL RF group (Postdoctoral fellowship advisor) |

**Dr. Michael A. Jaworski Biographical Sketch**

Education:

| | | |
|---|---|---|
| University of Illinois at Urbana-Champaign | Mechanical Engineering | B.S. 2002 |
| University of Illinois at Urbana-Champaign | Nuclear Engineering | M.S. 2006 |
| University of Illinois at Urbana-Champaign | Nuclear Engineering | Ph.D. 2009 |

Appointments:

Aug. 2009-Feb. 2010. - Post-doctoral research associate University of Illinois at Urbana-Champaign
Feb. 2010-present - Associate research physicist Princeton Plasma Physics Laboratory
Jan. 2011-present - NSTX Lithium Research Topical Science Group Deputy Leader

Relevant Publications in Liquid Metals and Plasma-Material Interactions Research:

M.A. Jaworski, T.K. Gray, M. Antonelli, J.J. Kim, C.Y. Lau, M.B. Lee, M.J. Neumann, W. Xu, D.N. Ruzic, "Thermoelectric magnetohydrodynamic stirring of liquid metals", Physical Review Letters, **104** (2010) 094503.

M.A. Jaworski, N.B. Morley, D.N. Ruzic, "Thermocapillary and thermoelectric effects in liquid lithium plasma facing components", Journal of Nuclear Materials, **390-391** (2009) 1055.

M.A. Jaworski, S.P. Gerhardt, N.B. Morley, T. Abrams, R. Kaita, J. Kallman, H. Kugel, R. Majeski, D.N. Ruzic, "Macroscopic motion of liquid metal plasma facing components in a diverted plasma", Journal of Nuclear Materials, **415** (2011) S985.

W. Xu, V. Surla, M.A. Jaworski, M. Lee, T. Mui, M.J. Neumann, D.N. Ruzic, "Investigation of heat transfer in TEMHD driven swirling lithium flow", Journal of Nuclear Materials, **415** (2011) S981.

M.A. Jaworski, C.Y. Lau, D.L. Urbansky, M.B. Malfa, T.K. Gray, M.J. Neumann, D.N. Ruzic, "Observations of liquid lithium uptake in a porous molybdenum foam", Journal of Nuclear Materials, **378** (2008) 105.

M.A. Jaworski, M.G. Bell, T.K. Gray, R. Kaita, J. Kallman, H.W. Kugel, B. LeBlanc, A.G. McLean, S.A. Sabbagh, V.A. Soukhanovskii, D.P. Stotler, V. Surla, "Modification of the electron energy distribution function during lithium experiments on the National Spherical Torus Experiment", Fusion Engineering and Design, (2012) *in press.*

Synergistic Activities:

NSTX Lithium Research Topical Science Group deputy leader

Graduate and Post-Doctoral Mentor(s):

Dr. David N. Ruzic, University of Illinois at Urbana-Champaign

Collaborators Past 48 Months:

David Ruzic, V. Surla, and D. Andruczyk at University of Illinois at Urbana-Champaign, N.B. Morley at University of California - Los Angeles, R. Maingi, J. Canik, T.K. Gray A.G. McLean at Oak Ridge National Laboratory, J. Kallman, V. Soukhanovskii at Lawrence Livermore National Laboratories, M.J. Neumann at Soladigm Corp.

**Prof. BRUCE E. KOEL**

Professor of Chemical and Biological Engineering
Associated Faculty in Chemistry, MAE, and PRISM
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Princeton University
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### a. Professional Preparation

| | | |
|---|---|---|
| Emporia State University | Chemistry | B.S. (Highest Honors), 1976 |
| Emporia State University | Chemistry | M.S., 1978 |
| University of Texas, Austin | Chemistry | Ph.D., 1981 |
| University of California, Berkeley | Chemistry | Miller Postdoctoral Fellow, 1981-83 |

### b. Appointments

*Professor*, Department of Chemical and Biological Engineering, Princeton University, 2011—
*Associated Faculty*, Chemistry, MAE, and PRISM, Princeton University, 2011—
*NSTX Collaborator*, Princeton Plasma Physics Laboratory (PPPL), 2011—
*Adjunct Professor*, Department of Chemistry, Lehigh University, 2011
*Interim Vice President and Assoc. Provost for Research and Graduate Studies*, Lehigh Univ., 2008-2010
*Interim Vice Provost for Research*, Lehigh University, 2007-2008
*Professor*, Department of Chemistry, Lehigh University, 2005-2010
*Chairman*, Department of Chemistry, University of Southern California, 1998-2001
*Adjunct Professor*, Department of Materials Science, University of Southern California, 1995-2005
*Professor*, Department of Chemistry, University of Southern California, 1993-2005
*Associate Professor*, Department of Chemistry, University of Southern California, 1990-1993
*Associate Professor*, Department of Chemistry, University of Colorado, Boulder, 1989
*Fellow*, Cooperative Institute for Research in Environmental Sciences (CIRES), U. Colorado, 1983-1989
*Assistant Professor*, Department of Chemistry, University of Colorado, Boulder, 1983-1989
*Miller Postdoctoral Fellow*, University of California, Berkeley, 1981-1983

### c. Ten Related Publications (250 total)

1. *"STM and LEED observations of a c(2×2) Ge overlayer on Pt(100)"*, T. Matsumoto, M. Batzill, and B. E. Koel, *Surface Sci.,* **603(15)**, 2252-2262 (2009).
2. *"Adsorption and Reaction of Gaseous H (D) Atoms with D (H) Adatoms on Pt(111) and Sn/Pt(111) Surface Alloys"*, H. Busse, M. R. Voss, D. Jerdev, B. E. Koel, *Surface Sci.*, **490,** 133-143 (2001).
3. *"Adsorption of Thermal D Atoms on Sn/Pt(111) Surface Alloys"*, M. R. Voss, H. Busse, and B. E. Koel, *Surface Sci.*, **414**, 330-340 (1998).
4. *"Deuterium Dissociation on Ordered Sn/Pt(111) Surface Alloys"*, P. Samson, A. Nesbitt, B. E. Koel, and A. Hodgson, *J. Chem. Phys.*, **109**, 3255-64 (1998).
5. *"Trajectory-Dependent Neutralization of Low Energy $Li^+$ Scattered from Alkali Adsorbates on Ni(111)"*, L. Q. Jiang, Y. D. Li, and B. E. Koel, *Phys. Rev. Lett.*, **70**, 2649-2652 (1993).
6. *Chapter 2 "Structure, Characterization and Reactivity of Pt-Alloy Surfaces"*, B. E. Koel, in Model Systems in Catalysis, R. M. Rioux (Ed.), (Springer, 2010), pp. 29-50.

7. *"Studies of ethylene oxide adsorption on Pt-Sn alloys with TPD, HREELS, UPS and DFT calculations",* J. Kim, J. Fu, S. Podkolzin and B.E. Koel, *J. Phys. Chem. C* **114**, 17238-17247 (2010).
8. *"Formation of Pd monomers and dimers on a single crystal $Pd_3Fe(111)$ surface"*, X. Yang, J. Hu, R. Wu and B. E. Koel, *J. Phys. Chem. Lett.*, **1**(16), 2493-2497 (2010).
9. *"Formation and Structure of a (√19×√19)R23.4°-Ge/Pt(111) Surface Alloy"*, C.-S. Ho, S. Banerjee, M. Batzill, D. E. Beck, and B. E. Koel, *Surface Sci.*, **603**, 1161-1167 (2009).
10. *"Formation of Ge-Pt layer compound on Pt(100)"*, T. Matsumoto, C.-S. Ho, and B. E. Koel, *J. Phys. Chem. C*, **113(50)**, 21019-21021 (2009).

**d. Synergistic Activities (five selected)**

- Member, Science Advisory Committee (SAC) of the Center for Functional Nanomaterials (CFN) at Brookhaven National Laboratory (BNL), 2012—
- Member, Governing Board, Council for Chemical Research (CCR), 2011—
- George A. Olah Award in Hydrocarbon or Petroleum Chemistry, American Chemical Society, 2007
- Chair, American Vacuum Society (AVS) Surface Science Division, 2000 and 2001
- Chair, *Chemical Reactions at Surfaces* Gordon Research Conference, 1997

**e. Graduate Advisor:** John M. White, *UT-Austin* (deceased)
**Postdoctoral Sponsor:** Gabor A. Somorjai, *UC-Berkeley*

**f. Collaborators (last 48 months):** R.R. Adzic, *BNL*; S. Banerjee, *Tougaloo Coll.*; Robert Bartynski, *Rutgers*; M. Batzill, *U. S. Florida*; D.E. Beck, *Asylum*; A. Bugacov, *ISI*; D. Buttrey, *U. Delaware*; J. Chen, *U. Delaware*; S. Chen, *UC-Santa Cruz*; W. Chen, *Rutgers U.*; T. Felter, *SNL, Livermore*; T. Feng *Rutgers U.*; A. Frenkel, *Yeshiva U.*; R. Gagler, *USC*; R. Gorte, *U. Penn*; Q. He, *LBNL*; A. Herzing, *LU*; A. Hightower, *Occidental College*; C.-S. Ho, *Tunghai U., Taiwan*; S. Hsieh, *Nat'l Sun Yat-Sen U., Taiwan*; J. Hu, *UC-Irvine*; M. J. Janik, *Penn. State U.*; J. Jiao, *U. Wisconsin, Madison*; C. Kiely, *LU*; J.-H. Kim, *LAM Res. Corp.*; R. M. Kostecki, *LBNL*; J. Lahiri, *U. S. Florida*; Q. Li, *LU*; G.F. Liu; T. Matsumoto, *Nat'l Inst. of Nat. Sci., Okazaki, Japan*; M. Mavrikakis, *U. Wisconsin, Madison*; A. Mayernick, *Penn. State U.*; S. L. Morrow, *U. S. Florida*; S. Mukerjee, *Northeastern U.*; A. Olivas, *CCMC-UNAM, Ensenada, México*; G. Peng, *U. Wisconsin, Madison*; M.D. Perez; S. Podkolzin, *Stevens Institute of Technology*; N. Ramaswamy, *Northeastern U.*; X. Ren, *Army Res. Lab*; E.C. Samano, *CCMC-UNAM, Ensenada*; M. Snyder, *LU*; A. C. T. van Duin, *Penn. State U.*; R. Vasic, *Yeshiva U.*; J. Vohs, *U. Penn*; M. Vukmirovic, *BNL*; I. Wachs, *LU*; H. Wang, *Columbia U.*; P. Will, *USC-ISI*; Ruqian Wu, *UC Irvine*; W.-X. Zhang, *LU*; H. Zhao, *Huntsman Adv. Tech. Ctr.*; W.-P. Zhou, *BNL*.

**g. Students and postdoctoral associates, last 5 ys. (43 PhD, 7 MS students, and 26 postdocs total)**

Thesis Advisor: C. Allen, *PU*; O. Fasoranti, *PU*; C.B. Fish, *Picatinny Arsenal*; J. Fu, *PU*; E. Gauthier, *PU*; J. Martin, *RSI Silicon Products*; M. Ramos, *LU*; R. Sullenberger, *PU*; L. Welch, *LU*; S. Wulfsberg, *PU*; X. Yang, *LU*; P. Zhao, *PU*.

Postgraduate-Scholar Sponsor:J.-H. Kim, *LAM Res. Corp.*; G. Liu; A. Xiang, *PU*; W. Yan, *Texas Tech U.*; X. Yang, *U. Delaware*

## Dr. Daren Stotler

Princeton Plasma Physics Laboratory, Princeton University
Princeton NJ 08543-0451
Phone: 609-243-2063, Email: dstotler@pppl.gov


Dr. Daren Stotler is currently a Principal Research Physicist in the Theory Department of the Princeton Plasma Physics Lab. Dr. Stotler is principally interested in the interaction between plasmas and their material surroundings. In an experiment or reactor, those interactions result in the release of atoms and molecules into the plasma. These electrically neutral particles can freely cross the magnetic field lines of the experiment, perhaps resulting in a deterioration of its performance. Dr. Stotler worked with Dr. Charles Karney to develop the DEGAS 2 neutral gas transport code to study how the plasma-material interactions and the resulting particles affect current experiments and predict their impact on future devices. Code verification and validation have been a key component of that effort. Dr. Stotler has exploited the flexibility and parallelization capability designed into DEGAS 2 to simulate in detail the neutral particle transport in experiments carried out on the Alcator C-Mod tokamak at MIT and the National Spherical Torus Experiment (NSTX) at PPPL. This work includes detailed three-dimensional DEGAS 2 simulations of the diffusive evaporation of lithium in NSTX that match the experimental observations to within the estimated errors. As part of PPPL's participation in the Center for Plasma Edge Simulation project (2005 – present), Stotler has developed a comprehensive neutral particle transport routine based on DEGAS 2 and integrated it into the CPES kinetic plasma transport code.

### Education

- Ph.D., Applied Physics, University of Texas at Austin, Austin, TX, 1986
- B.A. (Summa cum Laude), Physics / Materials Science, Rice University, Houston, TX, 1981

### Professional Appointments

- Research Staff, Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ, 1986-present (currently Principal Research Physicist)
- Member, Edge Coordinating Committee, 2004–present.
- Member, U. S. Burning Plasma Organization task group on verification and validation, 2006-2008
- Leader, PPPL Boundary Physics Science Focus Group, 1998–2004

### Selected Publications


Weigang Wan, Scott E. Parker, Yang Chen, Gun-Young Park, Choong-Seock Chang, and Daren Stotler, "The Pinch of Cold Ions from Recycling in the Tokamak Edge Pedestal", *Phys. Plasmas* **18**, 056116 (2011). [doi:10.1063/1.3589467]

**Dr. Robert Kaita Biographical Sketch**

Education and Training:

1973: Bachelor of Science (Departmental Honors in Physics)
State University of New York at Stony Brook, Stony Brook, NY

1978: Doctor of Philosophy (Thesis in Experimental Nuclear Physics)
Department of Physics, Rutgers University, New Brunswick, NJ

1978-1980: Postdoctoral Research Fellow (Experimental Plasma Physics)
Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ

Research and Professional Experience:

1990-Present: Principal Research Physicist, Princeton Plasma Physics Laboratory (PPPL)

2009-Present: Deputy Head of Lithium Research Task Group, National Spherical Torus Experiment (NSTX), PPPL

2004-2005: Edge Boundary & Physics Experimental Task Group Head, NSTX, PPPL

1999-2004: Task Leader, DOE Advanced Power Extraction Program

1997-Present: Co-Principal Investigator, Current Drive Experiment-Upgrade (CDX-U) and Lithium Tokamak Experiment (LTX), PPPL

1995-Present: Head of Diagnostic Operations, NSTX Spherical Torus, PPPL

1990-1994: Deputy Head and Co-Principal Investigator on the Princeton Beta Experiment-Modification (PBX-M) Tokamak, PPPL

1984-1990: Research Physicist, PPPL, Princeton Beta Experiment (PBX) and Tokamak Fusion Test Reactor (TFTR) diagnostics development

1980-1984: Staff Research Physicist, PPPL, energetic ion physics research on Princeton Large Torus (PLT) and Poloidal Divertor Experiment (PDX)

Publications:

1. R. Kaita, P. Efthimion, D. Hoffman, B. Jones, H. Kugel, R. Majeski, T. Munsat, S. Raftopoulos, G. Taylor, J. Timberlake, V. Soukhanovskii, D. Stutman, M. Iovea, M. Finkenthal, R. Doerner, S. Luckhardt, R. Maingi, R. Causey, "Diagnostics for Liquid Lithium Experiments in CDX-U," Rev. Sci Instrum. **72**, 915 (2001)

2. R. Kaita, R. Majeski, M. Boaz, P. Efthimion, B. Jones, D. Hoffman, H. Kugel, J. Menard, T. Munsat, A. Post-Zwicker, V. Soukhanovskii, J. Spaleta, G. Taylor, J. Timberlake, R. Woolley, L. Zakharov, M. Finkenthal, D. Stutman, G. Antar, R. Doerner, S. Luckhardt, R. Maingi, M. Maiorano, S. Smith, "Spherical Torus Plasma Interactions with Large-Area Liquid Lithium Surfaces in CDX-U," Fus. Eng. Des. **61-62**, 217 (2002)

3. R. Kaita, R. Majeski, M. Boaz, P. Efthimion, G. Gettelfinger, T. Gray, D. Hoffman, S. Jardin, H. Kugel, P. Marfuta, T. Munsat, C. Neumeyer, S. Raftopoulos, V. Soukhanovskii, J. Spaleta, G. Taylor, J. Timberlake, R. Woolley, L. Zakharov, M. Finkenthal, D. Stutman, L. Delgado-Aparicio, R. P. Seraydarian, G. Antar, R. Doerner, S. Luckhardt, M. Baldwin, R. W. Conn, R. Maingi, M. Menon, R. Causey, D. Buchenauer, M. Ulrickson, B. Jones, D. Rodgers, "Effects of large area liquid lithium limiters on spherical torus plasmas," J. Nucl. Materials **337-339**, 872 (2005)

4. R. Kaita, R. Majeski, R. Doerner, T. Gray, H. Kugel, T. Lynch, R. Maingi,

D. Mansfield, V. Soukhanovskii, J. Spaleta, J. Timberlake, L. Zakharov, "Extremely Low Recycling and High Power Density Handling in CDX-U Lithium Experiments," J. Nucl. Materials **363-365**, 1231-1235 (2007)
5. R. Majeski, R. Doerner, T. Gray, R. Kaita, R. Maingi, D. Mansfield, J. Spaleta, V. Soukhanovskii, J. Timberlake, and L. Zakharov, "Enhanced Energy Confinement and Performance in a Low Recycling Tokamak," Phys Rev. Lett. **97**, 075002-1-075002-4 (2006)
6. R. Kaita, R. Majeski, T. Gray, H. Kugel, D. Mansfield, J. Spaleta, J. Timberlake, L. Zakharov, R. Doerner, T. Lynch, R. Maingi, V. Soukhanovskii, "Low Recycling and High Power Density Handling Physics in CDX-U with Lithium Plasma-Facing Components," Phys. Plasmas **14**, 056111 (2007)
7. R. Kaita, L. Berzak, D. Boyle, T. Gray, E. Granstedt, G. Hammett, C. M. Jacobson, A. Jones, T. Kozub, H. Kugel, B. Leblanc, N. Logan, M. Lucia, D. Lundberg, R. Majeski, D. Mansfield, J. Menard, J. Spaleta, T. Strickler, J. Timberlake, J. Yoo, L. Zakharov, R. Maingi, V. Soukhanovskii, K. Tritz, and S. Gershman, "Experiments with Liquid Metal Walls: Status of the Lithium Tokamak Experiment," Fus. Eng. Des., **85**, 874 (2010)

Synergistic Activities
1. Overseeing NSTX lithium technology development laboratories at PPPL
2. Leading development of edge diagnostics on NSTX and LTX at PPPL
3. Collaborating with numerous institutions on lithium plasma-facing component research
4. Advising Princeton University engineering and chemistry students in surface science
5. Formulating protocols for safe handling of lithium at PPPL

Collaborators (within last 48 months)
1. J-P Allain and colleagues, Purdue University
2. N. Luhmann and colleagues, University of California at Davis
3. R. Majeski and LTX Team, PPPL
4. R. Maingi and colleagues, Oak Ridge National Laboratory
5. N. Nishino, Hiroshima University (Japan)
6. NSTX Team, PPPL
7. R. Nygren, Sandia National Laboratories (New Mexico)
8. A. Peebles and colleagues, University of California at Los Angeles
9. D. Ruzic and colleagues, University of Illinois at Urbana-Champaign
10. V. Soukhanovskii and colleagues, Lawrence Livermore National Laboratory (LLNL)
11. K. Tritz and colleagues, Johns Hopkins University
12. Q. Zang, Academia Sinica Institute of Plasma Physics (China)

Graduate Advisees (within last five years)
1. T. Gray (Ph. D., Princeton University, 2008), "Demonstration of Low Recycling on a Spherical Torus with Lithium Plasma Facing Components," Swarthmore College
2. L. Berzak (Ph. D., Princeton University, 2010), "Plasma Startup in a Spherical Tokamak with Close-fitting Conducting Walls," LLNL
3. J. Kallman (Ph. D., Princeton University, 2011) "Determination of Sheath Heat Transmission Coefficient in NSTX Discharges with Applied Lithium Coatings," LLNL

Postdoctoral Advisee (within last five years)
1. M. Jaworski (Ph. D., University of Illinois at Urbana-Champaign, 2009), PPPL

## Dr. Charles H. Skinner Biographical Sketch

**Education:**
Undergraduate: Physics Department, Imperial College U. of London, England, 1968-1971.
BSc. First Class Honors 1971, Associate of the Royal College of Science.
Graduate: Physics Department, Imperial College University of London, England, 1971-1974.
Ph. D. Awarded 1974, Diploma of Imperial College awarded 1974.

**Professional Appointments:**
1992-present. Principal Research Physicist, Princeton Plasma Physics Laboratory
1986-1992 Research Physicist, Princeton Plasma Physics Laboratory
1980-1986 Research Staff, Princeton Plasma Physics Laboratory.
1980 Visiting Scientist, Physikalisch-Techniche Bundesanstalt Berlin, W. Germany.
1978-1980 Research Associate, J.I.L.A. University of Colorado, Boulder Co.
1975-1977 Postdoctoral Research Fellow, Harvard, Cambridge Ma.

**Publications and Patents:**
Over 200 publications in refereed journals or conference proceedings (>60 1st author) and 20 Patents and Patent disclosures. Publications related to proposed project are:

1. "*Lithium wall conditioning and surface dust detection on NSTX*", invited talk at 13th International Conference on PFMC, C.H. Skinner, J.P. Allain, M.G.Bell, F.Q.L. Friesen, B. Heim, M.A. Jaworski, H. Kugel, R. Maingi, B. Rais, C.N. Taylor, Phys. Scr. T 145 (2011) 014020.
2. "*Deuterium Retention in NSTX with Lithium Conditioning*" C. H Skinner, J. P Allain, W Blanchard, H. W Kugel, R Maingi, L Roquemore, V Soukhanovskii, C. N Taylor, J. Nucl. Mater. 415 (2010) 5773-5776.
3. "*Continuous Improvement of H-Mode Discharge Performance with Progressively Increasing Lithium Coatings in the National Spherical Torus Experiment*." R. Maingi, S. M. Kaye, C. H. Skinner, D. P. Boyle, J. M. Canik, M. G. Bell, R. E. Bell, T. K. Gray, M. A. Jaworski, R. Kaita, H. W. Kugel, B. P. LeBlanc, D. K. Mansfield, T. H. Osborne, S. A. Sabbagh, and V. A. Soukhanovskii, Phys. Rev. Lett., 107, 145004 (2011)
4. "*The effect of progressively increasing lithium coatings on plasma discharge characteristics, transport, edge profiles, and ELM stability in the National Spherical Torus Experiment*." R. Maingi, D.P. Boyle, J.M. Canik, S.M. Kaye, C.H. Skinner, J.P. Allain, M.G. Bell, R.E. Bell, S.P. Gerhardt, T.K. Gray, M.A. Jaworski, R. Kaita, H.W. Kugel, B.P. LeBlanc, J. Manickam, D.K. Mansfield, J.E. Menard, T.H. Osborne, R. Raman, A.L. Roquemore, S.A. Sabbagh, P.B. Snyder, V.A. Soukhanovskii Nuclear Fusion at press (2012).
5. "*The Materials Analysis particle Probe (MAPP) Diagnostic System in NSTX*" Bryan Heim, S. Gonderman, C.N Taylor, J.P Allain, E. Yang, M. Gonzalez, E. Collins, C.H. Skinner, B. Ellis, W. Blanchard, L. Roquemore, H.W Kugel, R. Martin Proceedings of the 38th IEEE International Conference on Plasma Science (ICOPS) and 24th Symposium on Fusion Engineering (SOFE), Chicago, USA, June 26 through June 30, 2011IEEE Transactions on plasma science Vol. 40 (March 2012) p. 735 .

6. *"Tuning Fusion Plasma Behavior at the nanoscale on lithium-based surfaces."* P.S. Krstić, J.P. Allain, C.N. Taylor, J. Dadras, S. Maeda, K. Morokuma, J. Jakowski, A. Allouche, and C.H. Skinner, submitted to Nature Comm. April 2012.
7. *"Conference Report on the 2nd International Symposium on Lithium Applications for Fusion Devices"* M. Ono, M. G. Bell, Y. Hirooka, R. Kait, H. W. Kugel, G. Mazzitelli, J. E.Menard, S.V. Mirnov, M. Shimada, C. H. Skinner and F.L. Tabares Nuclear Fusion 52 (2011) 037001.
8. *"NSTX Plasma Response to Lithium Coated Divertor"* H.W. Kugel, M.G. Bell, J.P. Allain, R.E. Bell, S. Ding, S.P. Gerhardt, M.A. Jaworski, R. Kaita, J. Kallman, S.M. Kaye, B.P. LeBlanc, R. Maingi, R. Majeski, R. Maqueda, D.K. Mansfield, D. Mueller, R. Nygren, S.F. Paul, R. Raman, A.L. Roquemore, S.A. Sabbagh, H. Schneider, C.H. Skinner, V.A. Soukhanovskii, C.N. Taylor, J.R. Timberlake, W.R. Wampler, L.E. Zakharov, S.J. Zweben, and the NSTX Research Team, J. Nucl. Mater. 415 (2011) *S400*.
9. "*Recent Advances on Hydrogenic Retention in ITER's Plasma-facing materials: Be, C, W.*", C.H. Skinner, A.A. Haasz,V. Kh. Alimov, N. Bekris, R.A. Causey, R.E.H. Clark, J.P. Coad, J.W. Davis, R.P. Doerner, M. Mayer, A. Pisarev, J. Roth, T. Tanabe, Fus. Sci. Technol. **54** (2008) 891-945.
10. "*Plasma material interactions in current tokamaks and their implications for next step fusion reactors*". G. Federici, C. H. Skinner, J. N. Brooks, J. P. Coad, C. Grisolia, A. A. Haasz, A. Hassanein, V Phillips, C. S. Pitcher, J. Roth, W. R. Wampler, D. G. Whyte. Review in Nuclear Fusion, vol. 41, p.1967-2118, Dec 2001

**Professional Activities:**

I have been active in demonstrating innovative solutions to issues in plasma wall interactions. From studies of tritium retention issues on TFTR, I invented and demonstrated of a novel laser-based detritiation technique. Recently, I invented and demonstrated a novel electrostatic dust detector in the NSTX tokamak. I am currently developing a novel laser based method for cleaning first mirrors for ITER. On NSTX I am applying surface science analysis tools to understanding the interactions of lithiated surfaces with plasmas.

My professional appointments include:

- Leader of the NSTX Topical Science Group on Lithium Research.
- Leader of ITPA Diagnostic Specialist Working Groups in First Wall Diagnostics.
- Member of the ITPA Div/SOL group.
- Member of the IAEA Coordinated Research Program on Dust in Fusion Reactors.
- Member of the IAEA CRP on Tritium inventory in Fusion Reactors.

## Dr. Xueqiao Xu Biographical Sketch

Education and training:

Ph.D, University of Texas at Austin, Austin, TX, United States, 08/1990
M.A. Chinese Academy of Sciences, Institute of Plasma Physics, Hefei, Anhui, China, 11/1984

Research and Professional Experience:

01/1993-present, Physicist, Lawrence Livermore National Laboratory
04/2012-present, Guest professor of physics, Peking University, China
10/2006-present, Guangbiao (foundation) professor of physics, Zhejiang University, China
1990-1993: postdoctoral research associate, University of California, Berkeley, CA, United States

Relevant recent publication list:


1. X.Q. Xu, B.D. Dudson, P.B. Snyder, M.V. Umansky, H.R. Wilson and T. Casper, **Nonlinear ELM simulations based on a nonideal peeling–ballooning model using the BOUT++ code**, *Nucl. Fusion* **51** (2011) 103040.
2. X.Q.Xu, B.Dudson, P.B.Snyder, M.V.Umansky, and H.Wilson, **Nonlinear Simulations of Peeling-Ballooning Modes with Anomalous Electron Viscosity and their Role in Edge Localized Mode Crashes**, ***PHYSICAL REVIEW LETTERS*** , VOL. **105**, 175005 (2010).
3. X.Q.Xu, R.H.Cohen, T.D.ROGNLIEN, and J.R.Myra, **Low-High transitions simulations in Divertor Geometry, *Physics of Plasma*** , Vol. **7**, no. 5 1951-1958 (2000).
4. X. Q. Xu, and R. H. Cohen, **Scrape-off layer turbulence theory and simulations, *CONTRIBUTIONS TO PLASMA PHYSICS,*** V.38 Issue: 1-2, 158-170 (1998).
5. Xu XQ, Cohen RH, Porter GD, et al., **Turbulence studies in tokamak boundary plasmas with realistic divertor geometry, *Nuclear Fusion*** 40, 731(2000).
6. Xu XQ, Nevins WM, Rognlien TD, et al., **Transitions of turbulence in plasma density limits, *PHYSICS OF PLASMAS*** 10, 1773-1781(2003).
7. Russell DA, D'Ippolito DA, Myra JR, et al. W. M. Nevins, and X. Q. Xu,, **Blob dynamics in 3D BOUT simulations of tokamak edge turbulence**, ***PHYSICAL REVIEW LETTERS*** 93, 265001(2004).
8. Xu XQ, Nevins WM, Cohen RH, et al., **Dynamical simulations of boundary plasma turbulence in divertor geometry**, ***NEW JOURNAL OF PHYSICS*** 4, 53 (2002).
9. Xu XQ, Cohen RH, Nevins WM, et al., **Turbulence simulations of X point physics in the L-H transition, *NUCLEAR FUSION*** 42, 21-27(2002)**.**
10. Mazurenko A, Porkolab M, Mossessian D, J. A. Snipes, X. Q. Xu and W. M. Nevins, **Experimental and theoretical study of quasicoherent fluctuations in enhanced D-alpha plasmas in the Alcator C-Mod tokamak**, ***PHYSICAL REVIEW LETTERS*** 89, 225004(2002).
11. Snyder PB, Wilson HR, Xu XQ, **Progress in the peeling-ballooning model of edge localized modes: Numerical studies of nonlinear dynamics**, ***PHYSICS OF PLASMAS*** 12, 056115(2005).
12. X. Q. Xu, M. N. Rosenbluth, and P. H. Diamond, **Electron-temperature-gradient-driven instability in tokamak boundary plasma**, ***Phys. Fluids*** *B5* , 2206 (1993).


Synergistic Activities

- Conducts pedestal, boundary/divertor physics research via simulation and analysis; he has lead development of BOUT, BOUT++, and TEMPEST, fluid, gyro-fluid, and gyro-kinetic edge codes
- Served as Past Chair for Executive Committee of The International Sherwood Fusion Theory Conference, 11/2010-11/2011
- Served as Chair for Executive Committee of The International Sherwood Fusion Theory Conference, 11/2009-11/2010
- Served as associate Editor, Communication in Computational Physics, 07/2008-present.

| Collab. Institution | Collaborator Names |
|---|---|
| ANL | L. McInnis, H. Zhang |
| General Atomics | E. Belli, J. Candy, R. Groebner, T. Osborne, P. Snyder |
| LLNL | R. Cohen, A. Dimits, M. Dorr, M. Fenstermacher, I. Joseph, J. Hittinger, C. Lasnier, W. Nevins, T.D. Rognlien, D. Ryutov, M. Umansky, E.Wang |
| MIT | J. Hughes, B. LaBombard, M. Porkolab |
| ORNL | R. Maingi |
| UCSD | P Diamond |
| U Colorado | S Parker |
| U York | B. Dudson, H Wilson |
| IPP, China | X Gao |
| SWIP China | J Q Dong |
| WCI, Dajeon, Korea | H Jhang, SS Kim |
| POSTECH, Korea | H Park, G S Yun |

Graduate and Postdoctoral advisors and Advisees:

| | |
|---|---|
| UT-Austin. | M N Rosenbluth (Ph.D. thesis advisors) |
| UC Berkley | C K Birdsall (Postdoctoral fellowship advisor) |

## Dr. Thomas D. Rognlien Biographical Sketch

Education and training:
Ph.D, Dept. of Electrical Engineering, Stanford University, 1973
Thesis title: "Low frequency macroscopic instabilities of a fully ionized magnetoplasma"
M.S., Dept. of Electrical Engineering, Stanford University, 1969
B.E.E., Dept. of Electrical Engineering, University of Minnesota, 1967

Research and Professional Experience:
1975-present: Physicist & Deputy Leader for MFE Theory/Computation group, Lawrence Livermore National Lab, Livermore, CA
1974-1975: Postdoctoral research associate, Physics Dept., Univ. Colorado, Boulder, CO
1972-1974: National Research Council postdoctoral fellow, NOAA, Boulder, CO
Fellow, American Physical Society

Relevant recent publication list:


1. A. Yu. Pigarov, S.I. Krasheninnikov, and T.D. Rognlien, "New approach in two-dimensional fluid modeling of edge plasma transport with high intermittency due to blobs and edge localized modes," Phys. Plasmas **18** (2011) 092503.
2. A.Y. Pankin, A. Pletzer, Alex, S. Vadlamani et al., "Simulation of anomalous transport in tokamaks using the FACETS code Source," Computer Physics Comm. **182** (2011) 180.
3. J.D. Callen, R.J. Groebner, T.H. Osborne, J.M. Canik, L.W. Owen, A.Y. Pankin, T. Rafiq, T.D. Rognlien, W. Stacey, "Analysis of pedestal plasma transport," Nucl. Fusion **50** (2010) 064004.
4. T.D. Rognlien, R.H. Bulmer, M.E. Rensink, and J.N. Brooks, "Scrape-off layer plasmas for ITER with 2nd X-point and convective transport effects," J. Nucl. Mater. **363-365** (2007) 658.
5. Z. Xiong, R.H. Cohen, T.D. Rognlien, X.Q. Xu, "A high-order finite-volume algorithm for Fokker-Planck collisions in magnetized plasmas," J. Comp. Phys. **227** (2008) 7192.
6. T.D. Rognlien, "Understanding of edge plasmas in magnetic fusion devices," Plasma Phys. Contr. Fusion **47** (2005) A283.
7. T.D. Rognlien, M.V. Umansky, X.Q. Xu et al., "Simulation of plasma fluxes to material surfaces with self-consistent edge turbulence and transport for tokamaks," J. Nucl. Mater. **337-339** (2005) 327.
8. T.D. Rognlien, M.V. Umansky, X.Q. Xu, R.H. Cohen, "Self-consistent simulation of turbulence and transport in tokamak edge plasmas," Contrib. Plasma Phys. **44** (2004) 188.
9. T.D. Rognlien and M.E. Rensink, "Impurity transport in edge plasmas with application to liquid walls," Phys. Plasmas **9** (2002) 2120.
10. T.D. Rognlien, X.Q. Xu, and A.C. Hindmarsh, "Implementation of parallel implicit methods for edge-plasma numerical simulations," J. Comp. Phys. **175** (2002) 249.


Synergistic Activities
1. Conducts boundary/divertor physics research via simulation and analysis; he has lead development of UEDGE and utilized BOUT, TEMPEST, and COGENT edge codes
2. Serves as a US member of the International Tokamak Physics Activity (ITPA) Pedestal and Edge Physics group (2002 - present)
3. Serves on the Executive Committee of the US Transport Task Force for the edge plasma area
4. Serves as a member of the BPO Council (2011 – present)
5. Served as leader/deputy leader of DOE OFES BPO Boundary Topical Group (2006-11)

| Collab. Institution | Collaborator Names (last 48 months) |
|---|---|
| ANL | M. McCourt, L. McInnis, H. Zhang |
| EURATOM/JET | M. Groth |
| General Atomics | E. Belli, R. Groebner, T. Osborne, P. Snyder |
| Georgia Tech | W. Stacey |
| Tech-X | J. Cary, A. Pankin, S. Kruger |
| LLNL | S. Allen, B. Cohen, R. Cohen, M. Dorf, M. Dorr, M. Fenstermacher, I. Joseph, D. Hill, J. Hittinger, C. Lasnier, M. Makowskii, J. Marian, W. Nevins, D. Ryutov, V. Soukhanovskii, M. Umansky, X. Xu |
| MIT | D. Brunner, J. Hughes, B. LaBombard, D. Whyte |
| ORNL | R. Maingi, L. Owen |
| PPPL | A. Hakim, G. Hammett, D. Stotler |
| Purdue U. | J.P. Allain, J. Brooks, A. Hassanein |
| UCSD | J. Boedo, S. Krasheninnikov, Yu. Pigarov, R. Smirnov |

## Dr. Tom Petrie Biographical Sketch

DIII-D staff scientist
General Atomics, Sand Diego, CA
Years of Experience with Tokamak physics-related issues: 35

**Education:**

| Degree | Year | Discipline | Institution |
|---|---|---|---|
| Ph.D. | 1977 | Physics | University of Illinois |
| M.S. | 1972 | Physics | University of Illinois |
| B.S. | 1970 | Physics | Illinois Institute of Technology |

**Present research responsibilities:**

Recent responsibilities include the planning, execution, and analysis of DIII-D tokamak experiments which focus on particular aspects of divertor physics, such as density limits and optimizing plasma performance at higher density. His present research involves evaluating how changes in the divertor topology can affect overall plasma performance.

**Previous experience in tokamak physics – related tasks**

**1999 to present–** Dr. Petrie has been primarily involved with a wide range of issues related to divertor physics, including particle control in divertor plasmas, heat flux reduction at divertor targets, and the effects of variation in divertor geometry on divertor behavior, particularly as applied to high performance H-mode plasmas in tokamak.. Dr. Petrie has also been involved in divertor physics of several tokamak reactor design projects, including the ARIES series.

**1986 to 1999 –** Dr. Petrie has specialized in plasma radiation and heat flux measurements of DIII–D plasmas.

**1984 to 1986** - Dr. Petrie was task leader charged with the design modification of the DIII bolometer system for installation on DIII–D.

**1979 to 1984** - Dr. Petrie was involved mainly in the energy confinement studies of DIII plasmas, specializing in plasma radiation measurements and heat flux measurements.

**1977 to 1980** - Dr. Petrie was involved in the design studies of the General Atomics TNS and DEMO tokamak reactor, specializing in plasma transport simulations.

**Relevant Publications:**


1. T.W. Petrie, T.E. Evans, N.H. Brooks, M.E. Fenstermacher, J.R. Ferron, C.T. Holcomb, B. Hudson, A.W. Hyatt, T.C. Luce, C.J. Lasnier, S. Mordijck, R.A. Moyer, T.H. Osborne, P.A. Politzer, M.E. Rensink, M.J. Schaffer, P. B. Snyder, and J.G. Watkins, *Results from Radiating Divertor Experiments with RMP RLM Suppression and Mitigation*, Nucl. Fusion **51** (2011) 073003.
2. T.W. Petrie, T.E. Evans, M.E. Fenstermacher, S. Mordijck, N.H. Brooks, J.R. Ferron, B. Hudson, A.W. Hyatt, C.J. Lasnier, A.W. Leonard, T.C. Luce, R.A. Moyer, P.A. Politzer, M.J. Schaffer, P.B. Snyder, and J.G. Watkins, *First results examining the compatibility ofn RMP ELM Suppression with the radiating divertor in DIII-D*, J. Nucl. Mater. 415 (2011) S906.
3. T.W. Petrie, G.D. Porter, N.H. Brooks, M.E. Fenstermacher, J.R. Ferron, M.Groth, A.W. Hyatt, R.J. La Haye, C.J. Lasnier, A.W. Leonard, T.C. Luce, P.A. Politzer, M.E. Rensink, M.J. Schaffer, M.R. Wade, J.D. Watkins, and W.P. West, *Impurity behavior under puff-and-pump radiating divertor conditions*, Nucl. Fusion **49** (2009) 065013.
4. T.W. Petrie, N.H. Brooks, M.E. Fenstermacher, M. Groth,A.W. Hyatt, R.C. Isler, C.J. Lasnier, A.W. Leonard, G.D. Porter, M.J. Schaffer, J.G. Watkins, M.R. Wade, and W.P. West, *Comparison of Radiating Divertor Behavior in Single-null and Double-null Plasmas in DIII-D*, Nucl. Fusion **48** (2008) 045010.
5. T.W. Petrie, N.H. Brooks, M.E. Fenstermacher, M. Groth, A.W. Hyatt, C.J. Lasnier, A.W. Leonard, G.D. Porter, M.J. Schaffer,, M.R. Wade, ,J.G. Watkins, W.P. West, *Sensitivity of Injected argon*

*behavior to changes in magnetic balance in double-null plasmas in DIII-D*, J. Nucl. Mater. **390-391** (2009) 242.
6. T.W. Petrie, M.R. Wade, N.H. Brooks, M.E. Fenstermacher, M. Groth, A.W. Hyatt, R.C. Isler, C.J. Lasnier, A.W. Leonard, M.A. Mahdavi, G.D. Porter, M.J.Schaffer, J.G. Watkins, and W.P. West, *Compatibility of the radiating divertor with high performance Plasmas in DIII-D,* J. Nucl. Mater. **363-365** (2007) 416.
7. T.W. Petrie, S.L. Allen, N.H. Brooks, M.E. Fenstermacher, J.R. Ferron, C.M. Greenfield, M. Groth, A.W. Hyatt, M.A. Mahdavi, G.D. Porter, M.E. Rensink, M.J. Schaffer, M.R. Wade, and J.G. Watkins, *Variation of particle control with Changes in Divertor Geometry*. Nucl. Fusion **46** (2006) 57.
8. T.W. Petrie, J.G. Watkins, L.L. Lao, and P.B. Snyder, *The role of magnetic geometry on the poloidal distribution of ELM-induced peak particle flux at the divertor targets in DIII-D*, Nucl. Fusion **43** (2003) 910.
9. T.W. Petrie, J/G. Watkins, L.R. Baylor, N.H. Brooks, M.E. Fenstermacher, A.W. Hyatt, G.L. Jackson, C.J. Lasnier, A.W. Leonard, A. Pigarov, M.E. Rensink, T.D. Rognlier, M.J. Schaffer, N.S. Wolf, *Changes in Edge and Scrape-off Layer Plasma Behavior Due to Variation in Magnetic Balance in DIII-D*, J. Nucl. Mater. **313-316** (2003) 834.
10. T.W. Petrie, C.M. Greenfield, R.J. Groebner, A.W. Hyatt, R.J. La Haye, A.W. Leonard, M.A. Mahdavi, T.H. Osbourne, M.J. Schaffer, D.M. Thomas, W. P. West, S.L. Allen, M.E. Fenstermacher, C. J. Lasnier, G.D. Porter, N.S. Wolf, J.G. Watkins, T.L.Rhodes, *The effect of divertor balance on H-mode performance in DIII-D,* J. Nucl. Mater. 290-293 (2001) 935.

**Synergistic Activities:**

Dr. Petrie has led experiments on DIII-D in the last ten years that have produced:

1. Study of the effect of divertor shaping on the behavior of high density and radiating divertor tokamak plasmas.
2. Study of the effect of divertor shaping on particle control in tokamaks.
3. Study of the effect of resonant magnetic perturbations on ELM mitigation and heat flux reduction.
4. Study of divertor geometry on heat flux reduction.
5. Study of magnetic balance on divertor and core plasma behavior

**Collaborators in the last 48 month period:**

N.H. Brooks, *General Atomics* (retired), J. Canik, *Oak Ridge National Laboratory*, T.E. Evans, *General Atomics*, M.E. Fenstermacher, *Lawrence Livermore National Laboratory*, J.R. Ferron, *General Atomics*, M. Groth, *Lawrence Livermore National Laboratory*, D.N. Hill, *Lawrence Livermore National Laboratory*, C.T. Holcomb, *Lawrence Livermore National Laboratory*, B. Hudson, *University of California, San Diego*, A.W. Hyatt, *General Atomics*, R.J. La Haye, *General Atomics*, T.C. Luce, *General Atomics*, C.J. Lasnier, *Lawrence Livermore National Laboratory*, S. Mordijck, *University of William and Mary*, R.A. Moyer, *University of California, San Diego*, T.H. Osborne, *General Atomics*, G.D. Porter, *Lawrence Livermore National Laboratory* (retired), M.E. Rensink, *Lawrence Livermore National Laboratory* (retired), M.J. Schaffer, *General Atomics* (retired), P.C. Stangeby, *University of Toronto*, P. B. Snyder, *General Atomics*, M.R. Wade, *General Atomics* , J.G. Watkins, *Sandia National Laboratory*

## Dr. Alexei Pankin Biographical Sketch

### Alexei Y. Pankin – Tech-X

#### Education and Training

| | | |
|---|---|---|
| Institute for Nuclear Research, Ukraine | Ph.D. in Physics and Chemistry of Plasmas | 1999 |
| T.Shevchenko Kiev University | Hon. M.Sc. in Radiophysics (Electrical Engineering) | 1990 |

#### Research and Professional Experience

| | |
|---|---|
| 2010-to present | Principal Research Scientist, Tech-X Corporation, Boulder CO. |
| 2006-2010 | Principal Research Scientist, Lehigh University, Bethlehem PA. |
| 2004-2006 | Research Scientist, SAIC, San Diego CA. |
| 1999-2004 | Research Scientist, Lehigh University, Bethlehem PA. |
| 1995-1999 | Scientific Researcher, Institute for Nuclear Research Kiev, Ukraine. |
| 1992-1995 | Junior Scientific Researcher, Institute for Nuclear Research Kiev, Ukraine. |

#### Related and Recent Publications

- A. H. Hakim, T. D. Rognlien, ..., A.Y. Pankin *et al.*, Coupled core-edge simulations of H-mode buildup using the Fusion Application for Core-Edge Transport Simulations (FACETS) code *Phys. Plasmas* 19:032505 (2012).
- A.Y.Pankin, G. Park, J. Cummings *et al.*, Kinetic Modeling of H-mode pedestal with effects from anomalous transport and MHD stability. *"Problems of Atomic Science and Technology", Series "Plasma Physics"* 17(N1):8-12 (2011).
- A.Y. Pankin, A. Pletzer, S. Vadlamani *et al.*, Simulation of anomalous transport in tokamaks using the FACETS code. *Computer Physics Communications* 182(1):180-184 (2011).
- T. Rafiq, G. Bateman, A.H. Kritz, and A.Y. Pankin, Development of drift-resistive-inertial ballooning transport model for tokamak edge plasmas. *Phys. Plasmas* 17:082511 (2010).
- J.R. Cary, A. Hakim, ..., A. Pankin *et al.*, FACETS – A Framework for Parallel Coupling of Fusion Components. *Parallel, Distributed and Network-Based Processing (PDP) (18th Euromicro International Conference)* ISSN: 1066-6192, p. 435-442 (2010).
- J.D. Callen, R.J. Groebner, ..., A.Y. Pankin *et al.*, Analysis of pedestal transport. *Nucl. Fusion*, 50: 064004 (2010).
- A.H. Hakim, J.R. Cary, J. Candy, ..., A Pankin, *et al.*, Coupled whole device simulations of plasma transport in tokamaks with the FACETS code. *J. Physics: Conf. Series (2010).*
- P. Snyder, N. Aiba, ..., A. Pankin *et al.*, Pedestal stability comparison and ITER pedestal prediction. *Nucl. Fusion* **49**, 085035 (2009).
- T. Rafiq, A. Pankin, G. Bateman, A. Kritz, and F. Halpern, Simulation of electron thermal transport in H-mode discharges. *Phys. Plasmas* **16**, 032505 (2009).
- J. Cummings, A. Pankin, N. Podhorszki *et al.*, Plasma edge kinetic-MHD modeling in tokamaks using Kepler workflow for code coupling, data management and visualization. *Commun. Comput. Phys.* **4**, 675–702 (2008).

#### Collaborators

C. S. Chang, S. H. Ku (PPPL), C.R. Sovinec, D. Schnack, C. Hegna (U. Wisconsin), R. Groebner, J. Kinsey, P. Snyder (GA), D.P. Brennan (Tulsa U.), A. Kritz, T. Rafiq (Lehigh U.), X. Garbet, V. Parail, I. Voitsekhovitch (JET/Euratom/UKAEA, UK), A. S. Kukushkin, A. Polevoy (ITER), J. Cummings (Caltech).

## Prof. Jeffrey N. Brooks Biographical Sketch

Professor of Nuclear Engineering
Purdue University
West Lafayette, Indiana 47907
765-496-3630
brooksjn@purdue.edu

**Education**

| | | |
|---|---|---|
| Ph.D. | Electrical Engineering-1972 | New York University |
| MS | Electrical Engineering-1967 | New York University |
| BS | Electrical Engineering-1965 | New York University |

**Professional Experience**

- More than 30 years of experience in research and development in nuclear fusion engineering, computer simulation, and plasma science. Nationally and internationally recognized in the area of fusion plasma/material interaction and related modeling.
- Developed numerous advanced computer codes (REDEP, WBC, BPHI, etc.) to analyze 3-D, full kinetic, multi-process, sputtering erosion/redeposition, plasma contamination, tritium codeposition, component lifetime, atomic and molecular processes, sheath boundary physics, carbon and hydrocarbon chemical sputtering/transport, and associated phenomena, for fusion power, plasma processing, and related applications.
- Worked with major US and European fusion tokamak facilities (TFTR, NSTX, CMOD, DIII-D, TEXTOR, JET, etc.), design study groups (INTOR, ITER, etc.), and plasma lab facilities (PISCES, etc.), to predict and explain plasma/surface interaction results, and guide future experiments and designs.
- Co-invented the helium self-pumping concept for helium removal via trapping in deposited vanadium, nickel, or other selected materials. Tested concept successfully in TEXTOR tokamak (Julich Germany). Winner of IR-100 award for this work.
- Helped establish and strengthen US, European, and Japanese plasma/surface interaction modeling groups.

(Feb. 2008-present) Professor of Nuclear Engineering, Purdue University, West Lafayette, IN
- Fusion engineering, plasma/surface interaction modeling, computer simulation.

(1974-Feb. 2008) Senior Nuclear Engineer, Argonne National Laboratory, Argonne, IL
- Fusion engineering, plasma/surface interaction modeling, computer simulation.

(1972-1974) Member of Technical Staff, General Research Corporation, Denville, NJ
- Computer simulation, radar systems, nuclear weapons effects.

(1970-1972) Research assistant, teaching fellow, New York University, New York, NY
- Teaching, research.

(1967-1970) Staff Member, Loral Electronic Systems, New York, NY
- Microwave and antenna design, electronic warfare systems, computer simulation.

**Publications**

Author of more than 400 journal articles, reports, book-chapter

## Prof. Ahmed Hassanein Biographical Sketch

**Ahmed Hassanein**
**Purdue University**

***Education and Training***

| | | | |
|---|---|---|---|
| University of Wisconsin, Madison | Nuclear Engineering | Ph.D. | 1982 |
| University of Wisconsin, Madison | Physics | M.S. | 1981 |
| University of Wisconsin, Madison | Nuclear Engineering | M.S. | 1979 |

***Professional Experience***

(07/09-present) Head of Nuclear Engineering, Purdue University, West Lafayette, IN, USA

(04/09-present) Paul L. Wattelet Professor of Nuclear Engineering, Purdue University

(07/08-present) Director of the Center for Materials Under eXtreme Environment (CMUXE Lab)

(08/07-05/09) Professor of Nuclear Engineering, Purdue University, West Lafayette, IN

(2000-2007) Senior Nuclear Engineer and Group Leader, Argonne National Laboratory, IL

(2000-2007) Director of Fusion Power Program, Argonne National Laboratory

(1982-2000) Nuclear Engineer, Argonne National Laboratory

***Publications***

**Ten closely related publications (of more than 450 total)**

1. A. Hassanein, "*Liquid-metal targets for high-power applications: Pulsed heating and shock hydrodynamics*", Laser and Particle Beams 18, pp. 611-622 (2000).
2. A. Hassanein, "*Prediction of material erosion and lifetime during major plasma instabilities in tokamak devices*", Fusion Eng. Des. vol. 60, pp. 527 (2002).
3. Z. Insepov, J. Norem, D. R. Swenson, A. Hassanein, "*Surface erosion and modification by energetic ions*", Vacuum 82 872-879 (2008).
4. A. Hassanein, T. Sizyuk and I. Konkashbaev, "*Integrated simulation of plasma surface interaction during edge localized modes and disruptions: Self-consistent approach*", Journal of Nuclear Materials 390-91, 777-780 (2009).
5. V. Sizyuk and A. Hassanein, "*Damage to nearby divertor components of ITER-like devices during giant ELMs and disruptions*", Nuclear Fusion 50, 115004 (2010).
6. G. V. Miloshevsky and A. Hassanein, "*Modelling of Kelvin-Helmholtz instability and splashing of melt layers from plasma-facing components in tokamaks under plasma impact*", Nuclear Fusion 50, 115005 (2010).
7. V. Sizyuk and A. Hassanein, "*Self-consistent analysis of the effect of runaway electrons on plasma facing components in ITER*", Nuclear Fusion, vol. 49, N9, p. 095003 (2009).
8. V. Sizyuk, A. Hassanein and T. Sizyuk, '*Hollow laser self-confined plasma for extreme ultraviolet lithography and other applications*', Laser and Particle Beams 25, pp. 143-154, (2007).
9. A. Hassanein, "*Simulation of high power deposition on target materials: Applications in magnetic, inertial fusion and high power plasma lithographic devices*", Problems of Atomic Science and Technology: Plasma Physics 12, 130 (2006).

10. Y. Shi, G. V. Miloshevsky and A. Hassanein, "*Theoretical Studies of Macroscopic Erosion Mechanisms of Melt Layers Developed on Plasma Facing Components*" Journal of Nuclear Materials 412, 123 (2011).

***Synergistic Activities***

Editor of *Fusion Engineering and Design*, Modeling and Key Issues of Plasma/Surface Interactions in Future Tokamaks, 2002, Vol. 60/4;

Editor *Hydrogen and Helium Recycling at Plasma Facing Materials*, NATO Science Series, Vol. 54, 2002, Kluwer Academic Publishers.

Editor of *IEEE Transactions on Plasma science, Special Issue, 2012.*

Chair and member of several international committees on fusion energy and materials under extreme environments

Frequent reviewer of more than 20 Journals and professional organizations

**Prof. JEAN PAUL ALLAIN**
Associate Professor, School of Nuclear Engineering, Purdue University
Associate Professor, School of Materials Engineering by courtesy
Affiliate Faculty Member, Birck Nanotechnology Center
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(765) 496-9718 (voice), (765) 494-9570 (fax), E-mail: allain@purdue.edu

**Education and Training**

2001-2003: Postdoctoral Researcher, University of Illinois at Urbana-Champaign
2001 Ph.D. in Nuclear Engineering, University of Illinois Urbana-Champaign
2000 M.S. in Nuclear Engineering, University of Illinois Urbana-Champaign
1996 B.S. in Mechanical Engineering, California State Polytechnic University

**Research and Professional Experience**

2011- Present: Associate Professor of Nuclear Engineering, Purdue University
2011- Present: Associate Professor of Materials Engineering, Purdue University
2008- 2011 Assistant Professor of Materials Engineering (courtesy appointment), Purdue University
2008- Present: Affiliate Professor of Birck Nanotechnology Center, Purdue University
2007- 2011 Assistant Professor of Nuclear Engineering, Purdue University
2003-2007: Staff Scientist, Argonne National Laboratory

**Publications** (3 chapters, 65+ Journal Articles, 100+ Conference/Posters/Presentations)

**1. Relevant to Project**


- Osman El-Atwani, Dat V. Quach, Mert Efe, Patrick R. Cantwell, Bryan Heim, Bradley Schultz, Eric A. Stach, Joanna R. Groza and Jean Paul Allain, "High density bimodal distribution of pure consolidated tungsten with increased hardness via Spark Plasma Sintering", Materials Science and Engineering A, 528 (2011) 5670.
- B.Heim, C.N. Taylor, D.M. Zigon, S. O'Dell, J.P Allain, "Deuterium ion-surface interactions of liquid-lithium thin films on micro-porous molybdenum substrates", Nucl. Instrum. Methods in Phys. Res. B, 269 (2011) 1262.
- M. Nieto-Perez, J.P. Allain, Gonzalo Ramos, "Modeling of Surface Composition Dynamics in the ITER Divertor Region" IEEE Trans Plasma Science, 38 (2010) 414.
- J.N. Brooks, J.P. Allain, D.G. Whyte, R. Ochoukov, B. Lipschultz "Analysis of C-MOD molybdenum divertor erosion and code/data comparison", J. Nucl. Mater. 415 (2011) S112-S116.
- J.N. Brooks, J.P. Allain, R.P. Doerner, A. Hassanein, R. Nygren, T.D. Rognlien, and D.G. Whyte "Plasma surface interaction issues of an all-metal ITER", Nucl. Fusion, 49 (2009) 035007


**2. Five Other Significant Publications**


- J.P. Allain, et al., "IMPACT: a facility to study the interaction of low-energy intense charged particle beams with dynamic heterogeneous surfaces" Review of Scientific Instruments, 78 (2007) 113105.
- J.P. Allain and J.N. Brooks, "Simulation of the NSTX Liquid Lithium Divertor Module", Nuclear Fusion, 51 (2011) 023002

- J.P. Allain, J.N. Brooks, D.G. Whyte, "DiMES lithium erosion experiments under quiescent plasma conditions in DIII-D", Nuclear Fusion, 44 (2004) 655.
- S.S. Harilal, J.P. Allain, M.R. Hendricks, M. Nieto, A. Hassanein "Chemical state behavior of lithitated graphite surfaces," Applied Surface Science, 255 (2009) 8539.
- M. Nieto-Perez, J.P. Allain, B. Heim, C.N. Taylor, "Chemical and physical erosion of carbon and metallic substrates containing lithium during low-energy deuterium ion irradiation" J. Nucl. Mater. 415 (2011) S133-S136.

**Synergistic Activities**

- Invited DOE-Office of Fusion Energy Sciences ReNEW Panel Member 2008-2009
- Executive Committee member for Fusion Technology in the Nuclear and Plasma Sciences Society of IEEE, 2010-2014
- Served in the Fusion Neutron Science Pathways Committee focused on PMI and PFC issues
- Invited to the National Spherical Torus Experiment (NSTX) Programmatic Advisory Committee, 2011-2015
- *Guest Editor,* Transactions on Plasma Science, IEEE, 2009-2010, 2011-2012

**Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers**

Collaborators and Co-editors: J.N. Brooks (Purdue), N. Ghoneim (UCLA), A. Hassanein (Purdue), Robert Kaita (PPPL), H. Kugel (PPPL), P. Krstic (ORNL), R. Majeski (PPPL), R. Maingi (PPPL), F. Meyer (ORNL), D.N. Ruzic (U. Illinois), C. Skinner (PPPL), R. Stoller (ORNL), S. Sharafat (UCLA), M. Sawat (U. Wisconsin), A. Ying (UCLA), D. Youchison (SNLA), B. Wirth (U Tenn), M. Nieto-Perez (Cicata-IPN, Mexico)

Graduate and Postdoctoral Advisors: D.N. Ruzic (both PhD advisor and postdoc advisor) University of Illinois. Students graduated: Dan L. Rokusek (Sargeant Lundy, IL), Goujing Hou (U. Florida), G. Genco (Purdue University).

## Prof. Neil Morley Biographical Sketch


### NEIL B. MORLEY, Adjunct Professor

**Mechanical and Aerospace Engineering Dept.**
**UCLA, Box 951597, Los Angeles, CA 90095-1597**
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Professor Morley's research interests are in the areas of heat transfer, fluid dynamics, and fusion and fission reactor technology and design. Current topics of interest include tritium breeding and nuclear reactor cooling technologies; magnetohydrodynamics (MHD) of free surface and closed channel liquid metal flows in strong magnetic fields and with complex geometries; MHD and free surface effects on turbulence and turbulent heat transfer for flows of molten salts; and interactions between liquid metals and ceramic materials used as insulating barriers in fusion and fission energy systems.

**Education**

Ph.D./M.S., Nuclear Engineering, University of California, Los Angeles, 1994/1990
B.S., Electrical Engineering, University of New Mexico, 1988

**Positions**

2001 – Pres: Adjunct Professor and Research Engineer, University of California, Los Angeles, Mechanical and Aerospace Engineering Department
1997 – 2001: Research Engineer and Lecturer, University of California, Los Angeles, Mechanical and Aerospace Engineering Department
1995 – 1996: Post Doctoral Researcher, Commissariat a l'Energie Atomique, France, and University of California, Los Angeles, Mechanical and Aerospace Engineering Department

**Selected Synergistic Activities**

- National Steering Committee for OFES Plasma Facing Components Program (2003-Ongoing)
- Panel Leader for Power Extraction, Fusion Energy Sciences Research Needs Workshop (2008-2009)
- PAC Member for Plasma Science and Technology, Princeton Plasma Physics Laboratory (2008-ongoing)
- Editorial Advisory Board Member, Fusion Engineering and Design (2008 – ongoing)
- Task Coordinator, US/Japan TITAN and JUPITER-2 Collaboration (2004-2010)
- Principal Coordinator, US Test Blanket Module Program Planning Group (2005-2008)
- Technical Task Leader for R&D, Advanced Power Extraction (APEX) Design Study (1998-2003)

**Selected Publications (over 70 in archival literature)**


1. W.R. Meier, A.R. Raffray, R.J. Kurtz, N.B. Morley, W.T. Reiersen, P. Sharpe, S. Willms, "Findings of the US Research Needs Workshop on the Topic of Fusion Power," Vol. 85, pp.969-973 (2010).
2. N.B. Morley, A. Media and M.A. Abdou, "Measurements of specific electrical contact resistance between SiC and Lead-Lithium eutectic alloy," Fusion Science and Technology, Vol. 56, pp. 195-200 (2009).
3. A. Jaworski, N.B. Morley, D.N. Ruzic, Thermocapillary and thermoelectric effects in liquid lithium plasma facing components, Journal of Nuclear Materials, Vols. 390-391, pp. 1055-1058, (2009).
4. N. B. Morley, M.-J. Ni, R. Munipalli, P. Huang and M. A. Abdou, "MHD simulations of liquid metal flow through a toroidally-oriented manifold," Fusion Engineering and Design," Vol. 83, pp. 1335-1339 (2008).

5. N.B. Morley, Y. Katoh, S. Malang, B. Pint, A.R. Raffray, S. Sharafat, S. Smolentsev, G. E. Youngblood, "Recent research and development for the dual coolant blanket concept in the US," Fusion Engineering and Design, Vol. 83, pp. 920-927 (2008).
6. N.B. Morley, J. Burris, L. C. Cadwallader, M.D. Nornberg, Ga-In-Sn usage in the research laboratory, Review of Scientific Instruments, Vol. 79 (2008).
7. N. B. Morley and M. S. Tillack, Magnetohydrodynamics, chapter in the Standard Handbook for Electrical Engineers, 15th Edition, McGraw Hill, pp 11-96 – 11-130 (2006).
8. N. B. Morley, S. Malang, I. Kirillov, "Thermofluid Magnetohydrodynamic Issues for Liquid Breeders," Fusion Science and Technology, Vol. 47, No. 3, pp.488-501 (2005).
9. N. B. Morley, S. Smolentsev, R. Munipalli, M. Ni, D. Gao, M. Abdou, "Progress on the modeling of liquid metal, free surface, MHD flows for fusion liquid walls," Fusion Engineering and Design, Vol. 72, pp. 3-34 (2004).
10. N. B. Morley and J. Burris, "The MTOR LM-MHD flow facility, and preliminary experimental investigation of thin layer, liquid metal flow in a 1/R toroidal magnetic field," Fusion Technology, Vol. 44, pp. 74-78 (2003).

**Collaborators and Co-Authors (see list of papers for earlier co-authors)**

Abdou, MA – UCLA
Aithal, S. – Hypercomp
Anderson, M – U. Wisc.
Burris, J – UCLA
Calderoni, P – INL
Chernov, V - Bochvar Inst.
Fogarty, P – ORNL
Ghoniem, N – UCLA
Jaworski, M. - PPPL
Huang, P – Hypercomp
Katoh, Y – ORNL
Kunugi, T – Kyoto U.
Kimura, A – Kyoto U.
Kirillov, I - Efremov
Komori, S. – Kyoto U.
Konishi, S – Kyoto U.
Kurtz, R – PNL
Medina, A – UCLA
Malang, S – Consultant
Mann, T – ORNL
Meier, W – LLNL
Merrill, B – INL
Messadek, K – UCLA
Miraghaie, R. – Harvey Mudd
Moreau, R – Grenoble
Munipalli, R – Hypercomp
Muroga, T – NIFS
Nakaharai, H. – Kyushu U.
Narula, M – UCLA
Ni, MJ – UCLA
Nozawa, T – ORNL
Nygren, R – SNL
Pattison, M – Metaheurisitcs
Pint, B – ORNL
Premnath, KN – Metaheuristics
Raffray, R – UCSD
Reierson, W – ORNL
Reyes, S – LANL
Ruziz, D. – UIUC
Satake, S – Tokyo Univ Science
Sagara, A. – NIFS
Salavy, JF – CEA
Sawan, M – U. Wisc.
Sharafat, S – UCLA
Sharpe, P – INL
Smolentsev, S – UCLA
Snead, LL – ORNL
Song, KW – KAERI
Sviatoslavsky, G – U. Wisc.
Shinavski, R. – Hypertherm
Sze, DK – UCSD
Takeuchi, J – UCLA
Terai, T – Univ. Tokyo
Tourville, S – Consultant
Williams, B. – Ultramet
Willms, S – LANL
Windes, WE – INL
Wong, CPC – GA
Xu, ZY – SWIP
Ying, A – UCLA
Yokomine, T – Kyushu U.
Youssef, M – UCLA
Yuki, K – Tohoku U.
Zinkle, S. – ORNL
Zmitko, M – EFDA

**Graduate and Postdoctoral Advisees (past 5 years)**

Barra, Natasha; Burris, Jonathan; Gao, DH ; Konkachbaev, A; Medina, Albert ; Montalvo, Adam; Sutevski, Damien; Takeuchi, Junichi; Quan, Sandy

*ALICE A. YING,* **Deputy Director, UCLA Fusion Science and Technology Center**

**Education & Training**

| | | | |
|---|---|---|---|
| Ph.D. | Nuclear Engineering | University of Cincinnati | 1985 |
| M.S. | Nuclear Engineering | University of Cincinnati | 1982 |
| B.S. | Nuclear Engineering | Tsing-Hua University (Taiwan) | 1977 |

**Positions**

1999 – Pres: Deputy Director, UCLA Fusion Science and Technology Center
1993 – 1998: Senior Research Engineer (Specialist), UCLA
1988 – 1992: Research Engineer, UCLA
1985 – 1987: Research Associate, North Carolina State University, Raleigh, NC

**Publications**


1. X. Luo, A. Ying, M. Abdou, "Numerical Study of MHD Effect on Liquid Metal Free Jet under Complex Magnetic Fields," Fusion Engineering and Design, 81(8-14), 1451-1458, February 2006.
2. M. Narula, A. Ying, M. Abdou, "A Study of Liquid Metal Film Flow, Under Fusion Relevant Magnetic Fields," Fusion Science & Technology, 47(3), 564-568, April 2005.
3. X. Luo, M. Ni, A. Ying, M. Abdou, "Numerical Modeling for Multiphase Incompressible Flow with Phase Change", Numerical Heat Transfer B, 48:425–444 (2005).
4. T. Morikawa, A. Ying, J. Burris, M. Abdou, "Experimental Analysis of Soaker Hose Concept for First Wall/Divertor Application," Fusion Science & Technology, 47(3), 713-717, April 2005.
5. A. Ying, M. Abdou, N. Morley, T. Sketchley, R. Woolley, J. Burris, R. Kaita, P. Fogarty, H. Huang, X. Lao, et al., "Exploratory studies of flowing liquid metal divertor options for fusion-relevant magnetic fields in the MTOR facility," Fusion Engineering and Design, 72(1-3), 35-62, November 2004.
6. X. Luo, A. Ying and M. Abdou, "Experimental and Computational Simulation of Free Jet Characteristics Under Transverse Field Gradients", Fusion Science and Technology, 44:1, 85-93 (2003).
7. H. L. Huang, A. Ying and M. A. Abdou, "3D MHD free surface fluid flow simulation based on magnetic-field induction equations," Fusion Engineering and Design, Vol. 63-64 Pages 361-368, 2002.
8. A. Ying, T. Waku, D. L. Youchison, R. Hunt, H. G. Zhang, M. A. Ulrickson, "A subcooled boiling heat transfer predictive model for ITER EHF FW designs," Fusion Engineering and Design, doi:10.1016/j.fusengdes.2011.01.033
9. A. Ying, M. Abdou, H. Zhang, R. Munipalli, M. Ulrickson, M. Sawan, B. Merrill, Progress on an Integrated Multi-physics Simulation Predictive Capability for Plasma Chamber Nuclear Components, Fusion Eng. Des. (2010), doi:10.1016/j.fusengdes.2010.05.015
10. A. Ying, H. Zhang, D. Youchison, M. Ulrickson, 3D CFD Analysis of Subcooled Flow Boiling Heat Transfer with Hypervapotron Configurations for ITER First Wall Designs, Fusion Engineering and Design, (2010), DOI information: 10.1016/j.fusengdes.2010.03.040


**Synergistic Activities**

1. US Representative - IEA (International Energy Agency) Solid Breeder Sub-Task Group
2. US Key Person on U.S.-PRC Fusion Cooperation Program on Fusion Technology, 2004-present.
3. Executive Committee Member Fusion Energy Division, American Nuclear Society, 2008-2011.
4. Joint Task Coordinator for APEX (Advanced Power Extraction) Task I and ALIST (Application of Liquid Surface in Fusion Devices), 2001-2005.
5. Chief Scientific Investigator of Research Agreement No. USA 11641, IAEA Coordinated Research Project on Elements of Power Plant Design for Inertial Fusion Energy, 2001-2005.

**Collaborators and Co-Authors**

Akiba, M. (JAEA)
Anderson, M. (U. Wisc.)
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Boccaccini, L. (FZK)
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Moreau, R. (Grenoble)
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Sharpe, P. (INL)
Shimizu, A. (Kyushu U.)
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Song, KW (KAERI)
Strebkov, Y. (NIKIET)
Sze, DK (UCSD)
Szilard, R. (INL)
Tanaka, S. (U of Tokyo)
Terai, T. (U of Tokyo)
Tilikis, J. (KFI)
Ulrickson, M. (SNL)
Van der Laan, J. (NRG)
Wen, ZY (CAS)
Willms, S. (LANL)
Wilson, P. (U. Wisc.)
Wong, C. (GA)
Wu, Y. (ASIPP)
Xu, ZY (SWIP)
Yoder, G. (ORNL)
Yokomine, T. (Kyushu U.)
Youchison, D. (SNL)
Yuki, K. (Tohoku U.)
Zinkle, S. (ORNL)

**Graduate and Postdoctoral Advisees (past 5 years)**

Abou-Sena, Ali
Papp, Daniel
Young, Jack
Truong, Dinh
Di Sanzo, Christian
Hunt, Ryan
Narula, Manmeet
Reed, Robert
Zhang, Hongjie
An, Zhiyong
Guo, Wen
Liu, Haib

## Dr. Alexander Pigarov Biographical Sketch

Dr. Alexander Pigarov is Research Scientist at the University of California, San Diego. Research interests and expertise of Dr. Pigarov are in many areas: atomic and molecular physics; radiation transport; macroscopic transport of plasma, impurities, and neutral gas; plasma-wall interaction processes; low-temperature and non-ideal plasmas; dust in plasma environment; and physics/technology of fusion reactors. He participated in conceptual design studies of various magnetic fusion reactors. Dr. Pigarov has developed several sophisticated codes to study the plasma-neutral-radiation transport, dust dynamics, and particle transport in material surfaces.

*Education and training:*

1999 : Ph.D. in Physics and Chemistry of plasma,
Kurchatov Institute Atomic Energy, Moscow, Russia
1979 : M.S. Degree, Experimental/Theoretical Atomic Physics,
Moscow Engineering and Physics Institute, Moscow, Russia
1973-1979: Moscow Engineering and Physics Institute, Moscow, Russia

*Research and professional experience:*

2000-Pres.: from Assistant to full Research Scientist,
University of California at San Diego, La Jolla, CA
1996-2000: Associate Research Scientist, The College of William and Mary, Williamsburg, VA
1996 : Visiting Scientist, PSFC, Massachusetts Institute of Technology, Cambridge, MA
1995-1996: Visiting Scientist, Princeton Plasma Physics Laboratory, Princeton, NJ
1979-2006: from Junior to Senior Research Scientist,
Kurchatov Institute of Atomic Energy, Russia

*Selected Publications (total - more than 120 publications):*


1. A.Yu. Pigarov, P. Krstic, S.I. Krasheninnikov, R. Doerner, and T.D. Rognlien, "Dynamic models for plasma-wall interactions", Contributions Plasma Physics **52**, 465-477 (2012).
2. A.Yu. Pigarov, S.I. Krasheninnikov, T.D. Rognlien, "New approach in two-dimensional fluid modeling of edge plasma transport with high intermittency due to blobs and ELMs", Physics of Plasmas **18**, 092503 (2011).
3. A.Yu. Pigarov, S.I. Krasheninnikov, "Coupled plasma-wall modeling", Journal of Nuclear Materials **390-391**, 192-195 (2009).
4. A.Yu. Pigarov, S.I. Krasheninnikov, B. LaBombard, T.D. Rognlien, "Simulation of large parallel plasma flows in the tokamak SOL driven by cross-field transport asymmetries", Journal of Nuclear Materials **363-365**, 363 (2007).
5. A.Yu. Pigarov, S.I. Krasheninnikov, T.K. Soboleva, T.D. Rognlien, "Dust-particle transport in tokamak edge plasmas", Physics of Plasmas **12**, 122508 (2005).
6. A.Yu. Pigarov, E.M. Hollmann, S.I. Krasheninnikov, T.D. Rognlien, W.P West, "Multi-ion fluid simulation of tokamak edge plasmas including anomalous non-diffusive cross-field transport", Journal of Nuclear Materials **337-339**, 371 (2005).
7. A.Yu. Pigarov, S.I. Krasheninnikov, T.D. Rognlien, W.P. West, B. LaBombard, B. Lipschultz, R. Maingi, V. Soukhanovskii, "Multi-fluid code simulations including anomalous non-diffusive transport of plasma and impurities in the tokamak SOL", Contributions to Plasma Physics **44**, 228 (2004).
8. A.Yu. Pigarov, S.I. Krasheninnikov, W.P. West, T.D. Rognlien, J. A. Boedo, D.G. Whyte, C.J. Lasnier, T.W. Petrie, M.J. Schaffer, J.G. Watkins, "DIII-D Edge Plasma Simulations with

UEDGE code including non-diffusive anomalous cross-field transport", Journal of Nuclear Materials **313**, 1076 (2003).
9. A.Yu. Pigarov, "Collisional Radiative Kinetics of Molecular Assisted Recombination in Edge Plasmas", Physica Scripta **T96**, 16 (2002).
10. A.Yu. Pigarov, J. L. Terry, B. Lipschultz, "Study of the Discrete-to-Continuum Transition in Balmer Spectrum from Alcator C-Mod Divertor Plasmas", Plasma Physics Controlled Fusion **40**, 2055(1998).

*Synergistic Activities:*

- Acted as PI and Co-PI on Research Grants from different Federal Agencies.
- Reviewer for eight journals in the past ten years.
- Invention case SD2009-65 "Plasma disruption mitigation in fusion reactors by micro-explosions" is pending.
- Successively participated in several international collaborative projects in several conceptual design and technology studies (INTOR, IDEAL, ITER, OTR, GTRT, DEMO) and in the development of scientific codes (e.g. for FACETS SciDAC project) and commercial software.

*Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers.*

*Collaborators*: S.I. Krasheninnikov (UCSD), E.M. Hollmann (UCSD), J. Yu (UCSD), D. Rudakov (UCSD), D. Nishijima (UCSD), J.A. Boedo (UCSD), R. Doerner (UCSD), R.D. Smirnov (UCSD), D.J. Benson (UCSD), M. Rosenberg (UCSD), D.A. Mendis (UCSD), G. Tynan (UCSD), N.A. Pablant (UCSD), S.H. Muller (UCSD), N.H. Brooks (GA), T.C. Jernigan (GA), J.L. Terry (MIT), B. Lipschultz (MIT), A. Bader (MIT), R.S. Granetz (MIT), B. LaBombard (MIT), Y. Tanaka (Kanazawa Univ.), A.L. Roquemore (PPPL), C.H. Skinner (PPPL), N. Asakura (JAERI), T. Nakano (JAERI), P. Krstic (ORNL), S.J. Stuart (Clemson Univ.), J.R. Cary (Tech-X), S. Kruger (Tech-X), M. Miah (Tech-X), A. Pletzer (Tech-X), A. Hakim (Tech-X), S. Shasharina (Tech-X), R.H. Cohen (LLNL), T.D. Rognlien (LLNL), V. Soukhanovskii (LLNL), E.D. Marenkov (Mephi), A.A. Pisarev (Mephi), I.V. Tsvetkov (Mephi), T.K. Soboleva (Universidad Nacional Autónoma de México, Mexico), P. Shukla (Bochum University, Germany), A. Takayama (NIFS), Y. Tomita (NIFS)

*Graduate and Postdoctorial Advisors and Advisees.*

*Advisor*: V.A. Abramov (passed away), Kurchatov Institute Atomic Energy.

*Advisees*: B. Frolov, I.V. Dobrovolskaia, N. Moshmann.

## Prof. Sergei Krasheninnikov Biographical Sketch

Prof. Sergei Krasheninnikov is currently the leader of Applied Plasma Theory Group at the University California San Diego. Krasheninnikov's research interest includes plasma turbulence, transport, and plasma-wall interaction processes, laser-plasma interactions, atomic physics and dust dynamics in fusion related plasmas. Professor Krasheninnikov has served as chair of multiple committees for the American Physical Society, of which he is a fellow.

*Education and training:*

1992 Doctor of Science degree in Physics and Mathematics,
Kurchatov Institute Atomic Energy, Moscow, Russia
1980 Ph.D. in Physics and Chemistry of plasma,
Kurchatov Institute Atomic Energy, Moscow, Russia
1976 M.S. (with honor) from Moscow Institute of Physics and Technology, Moscow, Russia

*Research and professional experience:*

1999-Pres.: Professor, Mechanical and Aerospace Engineering Department,
University of California at San Diego, La Jolla, CA
1998-1999: Senior Research Scientist, Nuclear Engineering Department, Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA
1995-1998: Research Scientist, MIT Plasma Science and Fusion, MIT, Cambridge
1993-1995: Visiting Scientist, MIT Plasma Fusion Center, MIT, Cambridge
1992-1993: Invited Scientist, Centre Canadien de Fusion Magnetique, Montreal, Canada
1976-2006: from Junior to Leading Research Scientist,
Kurchatov Institute of Atomic Energy, Russia

*Selected Publications (total - more than 200 publications in refereed journals):*


1. E.D. Marenkov, S.I. Krasheninnikov, A.A. Pisarev, I.V. Tsvetkov, "On the tokamak first wall response to the ELM bursts", submitted to Physics of Plasmas (2012).
2. J. Angus, M. Umansky, and S. I. Krasheninnikov, "Effect of Drift Waves on Plasma Blob Dynamics" Physical Review Letters, to appear in May 2012.
3. J. Angus and S. I. Krasheninnikov "Drift Wave Dispersion Relation for Arbitrarily Collisional Plasma", Physics of Plasmas, to appear in June 2012.
4 A.Yu. Pigarov, P. Krstic, S.I. Krasheninnikov, R. Doerner, and T.D. Rognlien, "Dynamic models for plasma-wall interactions", Contributions Plasma Physics **52,** 465-477 (2012).
5. A.Yu. Pigarov, S.I. Krasheninnikov, T.D. Rognlien, "New approach in two-dimensional fluid modeling of edge plasma transport with high intermittency due to blobs and ELMs", Physics of Plasmas **18**, 092503 (2011).
6. E.D. Marenkov, S.I. Krasheninnikov, A.Yu. Pigarov, A.A. Pisarev, I.V. Tsvetkov, "On thermal instability caused by plasma-wall coupling", Physics of Plasmas **18,** 092502 (2011).
7. S.I. Krasheninnikov, R.D. Smirnov, D. L. Rudakov, "Dust in magnetic fusion devices", Plasma Physics Controlled Fusion **53**, 083001 (2011).

8. S.I. Krasheninnikov, D.A. D'Ippolito, J.R. Myra, "Recent theoretical progress in understanding coherent structures in edge and SOL turbulence", Journal of Plasma Physics **74**, 679 (2008).
9. R. P. Doerner, S. I. Krasheninnikov, and K. Schmid, "Particle-induced erosion of materials at elevated temperature", Journal of Applied Physics **95,** 4471 (2004).
10. S. I. Krasheninnikov, "On scrape off layer plasma transport", Physics Letters A **283,** 368 (2001).

*Synergistic Activities:*

2011-Pres.: Member of the Plasma Science Committee at the National Academies of Science

2007-Pres.: Member of the Scientific Advisory Committee of the International Conference on Physics of Dusty Plasma

2004-2005: Chair, International Workshop on "Dust in Fusion Plasmas", Napa, CA, April 5, 2005

2004-2010: Member of the DOE Edge Coordinating Committee

2002-2006: Co-Chair, Workshop "Electric Fields, Structures and Relaxation in Edge Plasmas"

2001-2009: Member of the International Tokamak Physics Activity (ITPA)

*Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers.*

*Collaborators*: A.Yu. Pigarov (UCSD), E.M. Hollmann (UCSD), J. Yu (UCSD), D. Rudakov (UCSD), D. Nishijima (UCSD), J.A. Boedo (UCSD), R. Doerner (UCSD), R.D. Smirnov (UCSD), D.J. Benson (UCSD), M. Rosenberg (UCSD), D.A. Mendis (UCSD), G. Tynan (UCSD), N.A. Pablant (UCSD), S.H. Muller (UCSD), N.H. Brooks (GA), T.C. Jernigan (GA), J.L. Terry (MIT), B. Lipschultz (MIT), A. Bader (MIT), R.S. Granetz (MIT), B. LaBombard (MIT), Y. Tanaka (Kanazawa Univ.), S. Zweben (PPPL), A.L. Roquemore (PPPL), C.H. Skinner (PPPL), N. Asakura (JAERI), T. Nakano (JAERI), P. Krstic (ORNL), S.J. Stuart (Clemson Univ.), J.R. Cary (Tech-X), S. Kruger (Tech-X), M. Miah (Tech-X), A. Pletzer (Tech-X), S. Shasharina (Tech-X), R.H. Cohen (LLNL), T.D. Rognlien (LLNL), V. Soukhanovskii (LLNL), M. V. Umansky (LLNL), J.R. Myra (Lodestar Research Co.), E.D. Marenkov (Mephi), A.A. Pisarev (Mephi), I.V. Tsvetkov (Mephi), A.I. Smolyakov (University of Saskatchewan, Canada), T.K. Soboleva (Universidad Nacional Autónoma de México, Mexico), P. Shukla (Bochum University, Germany), A. Takayama (NIFS), Y. Tomita (NIFS).

*Graduate and Postdoctorial Advisors and Advisees.*

*Advisor*: A.A. Ivanov (passed away), Kurchatov Institute Atomic Energy.

*Advisees*: G. Q. Yu, C. Estrada-Mila, E. Oyarzabal, B. Frolov, I.V. Dobrovolskaia, N. Moshmann, K Bodi, B. Paradkar, J. Angus, G. Cutler, R. Hajar

## Prof. David Ruzic Biographical Sketch

**Education and Training**

| | | | | |
|---|---|---|---|---|
| Undergraduate | Purdue University | Physics/App. Math | BS | 1979 |
| Graduate | Princeton University | Physics | MA | 1981 |
| | Princeton University | Physics | PhD | 1984 |

**Research and Professional Experience**

Bliss Professor, College of Engineering, 2011 - present
Affiliate in Micro and Nanotechnology Laboratory, 2008 - present
Director, Center for Plasma Material Interactions, 2004 - present
Associate Vice President for Administration, University Administration, 2002 - 2005
Faculty Fellow, Vice Presidents for Academic Affairs Office, 2000 - 2002
Assistant Dean, College of Engineering, Academic Programs, 1995-1996
Affiliate Faculty in Dept. of Electrical and Computer Engineering, 1991 - present
Professor, 1994 - present
Associate Professor, 1989-1994
Affiliate Faculty in Dept. of Material Science and Engineering, 1988 - 2002
Honors Faculty for Undergraduate Campus Honors Program, 1988 - present
Graduate Faculty in Physics, 1986 - present
Assistant Professor, 1984 - 1989
Research Staff I, Princeton University Plasma Physics Lab, Feb.1984 - June 1984
Research Assistant, Princeton University Plasma Physics Lab, 1979 - 1984

**Selected Honors**

Scientific Director, International Union of Vacuum Congresses, 2010
Campus Award for Excellence in Guiding Undergraduate Research, 2009
Fellow, American Vacuum Society, 2007
Fellow, American Nuclear Society, 2004
All-Campus Charles and Harriet Luckman Award for Distinguished Teaching, 1996
Presidential Young Investigator Award, 1985-1990, NSF

**Synergistic Activities**

Prof. Ruzic's Center is supported by the US Fusion program under three different contracts. The first is from Plasma Technology where Li interactions with materials and with high-heat fluxes are under investigation. The second is a grant in collaboration with ORNL to study the effects of ELMs and plasma "blobs" on the functioning of rf antenna. The third is for a diagnostic on NSTX. Illinois provided the Langmuir probe array located in the LLD and has personnel stationed at PPPL for its operation and analysis. In addition to fusion research Prof. Ruzic's Center works on industrial applications of plasma-surface interactions at atmospheric pressure and on a wide-range of semiconductor applications including EUV sources, magnetron sputtering, and plasma etching.

**Related Publications**

1. D.N. Ruzic, W. Xu, D. Andruczyk and M. A. Jaworski, "Lithium - Metal Infused Trenches (LiMIT) for Heat Removal in Fusion Devices", *Nuclear Fusion,* 52 pp102002-6 (2011)

2. V. Surla, M. Tung, W. Xu, D. Andruczyk, M. Neumann, D. N. Ruzic and D. Mansfield, "Seebeck Coefficient Measurements of Lithium Isotopes", *J. Nuc. Matter* 415 (2011) 18-22.
3. S. Jung, V, Surla, T, K. Gray, D. Andruczyk and D. N. Ruzic, "Characterization of a Theta-Pinch Plasma Using Triple Probe Diagnostics", *J. Nuclear Materials*, article in press (2011)
4. L. Meng, A.N. Cloud, S. Jung, D.N. Ruzic, "Study of plasma dynamics in a modulated pulsed power magnetron discharge using a time-resolved Langmuir probe", *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films* 29 011024, (2011)
5. M. A. Jaworski, T. K. Gray, M. Antonelli, J. J. Kim, C.Y. Lau, M. B. Lee, M. J. Neumann, W. Xu, and D. N. Ruzic, "Thermoelectric Magnetohydrodynamic Stirring of Liquid Metals" *Physics Review Letters*, 104, 094503 (2010).
6. K. Ibano, D. Ruzic, and V. Surla, "Sputtering and thermal evaporation studies of lithiated ATJ graphite," *IEEE Transactions on Plasma Science*, Vol. 38, No. 3 part 1, p 341-345 (2010).
7. V. Surla, M. A. Jaworski, T. K. Gray, K. Ibano, W. Xu, M. J. Neumann, and D. N. Ruzic, "Lithium research as a Plasma Facing Component Material at the University of Illinois" *Thin Solid Films*, Vol. 518, No. 22, pp. 6663-6666 (2010).
8. M. Jaworski, N.B. Morley, and D. N. Ruzic, "Thermocapillary and Thermoelectric Effects in Liquid Lithium Plasma Facing Components", *Journal of Nuclear Materials,* 390–391, pp. 1055-1058 (2009).
9. J. Sporre, C. H. Castano, R. Raju, and D. N. Ruzic, "Ionic Debris Measurement of Three Extreme Ultraviolet Sources," *Journal of Applied Physics*, 106, 4 (2009).
10. Ruzic, D. N., "Electric Probes for Low-Temperature Plasmas," AVS Monograph Series, New York (1994)

**Collaborators and Co-Editors last 4 years (other than students and post-docs who are listed below)**

Prof. J.P. Allain (Purdue University)
Dr. Denis Mansfield (PPPL)
Prof. Neil Morley (UCLA)
K. J. Park (and E. Ko, A. Dulkin, L. Wu, I. Karim, K. Leeser, S. Fields) (Novellus Systems)
G O'Sullivan, (and O Morris, P Hayden, P Dunne, F O'Reilly, E Sokell) (University College Dublin)

**Former Graduate Students and Postdoctoral advisees (last five years)**

Carlos Castano(Univ. Missouri); Matt Coventry (Starfire Industries); Randolph Faluta (SunPower); Travis Gray (ORNL); Kenzo Ibano (Univ. Kyoto); Mike Jaworski (PPPL); Robert Lofgren (INTEL); Wayne Lytle (Intel); Benjamin Masters (UIUC); Liang Meng (Novellus); Martin Neumann (Soladigmn); Wes Olczak (Sargent and Lundy); Huatan Qui (Novellus); Ramasamy Raju (TEL); Eithan Ritz(Micron); Benjamin Schultz (Intel); Hyung-Joo Shin (University of Houston); Joshua Spencer (UIUC); John Sporre(Sematech); Corey Struck (USAF); Keith Thompson (Hanford)

**Dr. Daniel Andruczyk Biographical Sketch**

Research Engineer/Scientist stationed at PPPL, Dept. Nuclear, Plasma and Radiological Engineering
Center for Plasma-Material Interactions
University of Illinois at Urbana-Champaign

Dr. Andruczyk is a University of Illinois Research Scientist/Engineer stationed at the Princeton Plasma Physics Labs. He was a Postdoctoral Researcher at the Center for Plasma-Material Interactions, a multidisciplinary center at the University of Illinois. Dr. Andruczyk conducts research into plasma edge studies and PFC materials, namely liquid lithium, as well as research related to manufacturing in the semiconductor industry. Dr. Andruczyk has previously worked at the Max Planck Institute for Plasma Physics, Greifswald where the W-7X Stellarator is being built. He has extensive expertise in plasma diagnostics including the development and running of diagnostic He Beams and has installed two on H-1NF Heliac in Canberra, Australia and the WEGA Stellarator in Greifswald, Germany.

**Academic Employment:**

Research Engineer, University of Illinois, Stationed at the Princeton Plasma Physics Laboratory, Mar. 2012 – Present.

Postdoctoral Research Scientist, University of Illinois Urbana-Champaign, Sept. 2010 - Feb. 2012.

Postdoctoral Research Scientist, Max Planck Institute for Plasma Physics, Greifswald, Sept. 2006 – July 2009.

Research Scientist, University of Sydney, Sept. 2005 – Aug. 2006.

**Education:**

| | | | |
|---|---|---|---|
| Ph.D: | Plasma Physics | University of Sydney | 2006 |
| B.S (Hons): | Laser Physics | University of Queensland | 1999 |
| B.S: | Physics | University of Queensland | 1998 |

**Most Relevant or Important Publications**

1. D. Andruczyk and D. N. Ruzic, Thermoelectric Properties of Lithium, Book Chapter, Book Title: Lithium Properties and Applications, Nova Books, at Publishers.

2. S. Jung, D. Andruczyk and D. N. Ruzic, Laboratory Investigations of Vapor Shielding for Lithium Coated Molybdenum in DEVeX, IEEE Trans. Plasma Sci. Vol. 40: No 3 March 2012.

3. D.N. Ruzic, W. Xu, D. Andruczyk and M. A. Jaworski, "Lithium - Metal Infused Trenches (LiMIT) for Heat Removal in Fusion Devices", *accepted in Nucl. Fusion Letts*, July 2011

4. V. Surla, M. Tung, D. Andruczyk, M. Neumann, D. N. Ruzic and D, Mansfield, Seebeck Coefficient Measurements of Lithium Isotopes, J. Nuc. Matter, 415 (2011) 18-22.

5. S. Jung, V. Surla, T.K. Gray, D. Andruczyk and D.N. Ruzic, J. Nuc. Mater. 415 (2011) S993–S99

6. D. Andruczyk, S. Namba, B. W James, K. Takiyama and T. Oda, A Short-Pulsed, Compact Supersonic Helium Beam for Plasma Diagnostics, Plasma Devices and Operation, **Vol 14** No 1, March 2006, 81-89.

7. S. Namba, K. Takiyama, D. Andruczyk, D. Ueno, S. Furukawa and B. W. James, Development of a Pulsed, Supersonic Helium Beam Source for Plasma Diagnostics, Jpn. J. Appl. Phys., **Vol 45** No 10B, (2006) pp8099-8130.

8. D. Andruczyk, R. N. Tarrant, B. W James, M. M. M. Bilek and G. W Warr, Langmuir Probe Study of a Titanium Pulsed Filtered Cathodic Arc Discharge, Plasma Sources Sci, Technol. **15** (2006) 533-537.