

DOE Final Technical Report (2009-2016):

DOE Grant Award Number: DE-SC0002040

Title: Research Projects for Interrogations of Biological Systems: Training for the Development of Novel Radiotracers

PI: Silvia S. Jurisson

Co-PIs: Susan Z. Lever and J. David Robertson

This grant was situated at the University of Missouri to train Ph.D. scientists in radiochemistry and synthetic chemistry in conjunction with Faculty from the Interdisciplinary Plant Group, Division of Biological Sciences, the MU Research Reactor Center, Molecular Biology and the Radiopharmaceutical Sciences Institute. This project was collaborative with Brookhaven National Laboratory (Richard Ferrieri, PI). Projects for the Ph.D. candidates included novel probe development for peptides, nucleosides, small molecules or radiometals, the direct use of radiometals as probes, or nuclear techniques for analysis. The projects for the postdoctoral fellow involved synthetic chemistry for the preparation of precursors for novel tracers that will be radiolabeled with ^{18}F or other appropriate radionuclides. The skill sets of our team members allowed us to prepare probes with positron or single photon emitters, as well as ones that are dual-labeled (fluorescent and radiolabeled). We focused our technical advances to those that will be broadly applicable to any research field.

Our program focused on fundamental training in radiochemistry and synthetic chemistry, followed by an interdisciplinary thesis project in a biological arena. Experiments were focused on “proof of principle” as we were asking ground-breaking questions. Probe development projects involve synthesis of precursor molecules, radiosynthesis and validation of the utility of these probes. We identified common needs to develop methods to label a variety of oligopeptides (radiometal chelators, growth factors, and receptor ligands) with carbon-11, fluorine-18, iodine-125 or radiometals, incorporation of radiolabels into aptamers discovered through selex and phage display, and small molecules such as the plant-growth regulator auxin (3-indoleacetic acid). We collaborated with Dr. Richard Ferrieri at Brookhaven National Lab (BNL), with an internship for the trainees, to carry out the C-11 labeling and imaging experiments. Plant transporter projects involve the use of radiometals (i.e., Fe-59, Ga-68, etc.) and/or radiolabeled probes (chelates) to determine the role(s) of the transporter, with potential extension to phytoremediation. Quantification of uptake and distribution of the metals or chelates was an important aspect of this training. Trace and essential (i.e., boron) element projects involve the use of radiolabeled trace/essential elements such as Fe-59, Mn-54 and Zn-65.

This grant involved several research projects focused on questions in biology that could be addressed by radiotracer methodology and non-invasive imaging techniques including (1) oligopeptide transporters (OPT); (2) small molecule probes of growth and development in plants: radiolabeled auxin analogues; (3) radiolabeling of aptamers for imaging and metabolism studies; (4) radiotracer methods to understand the movement of micronutrients from plants to insects; and (5) high specific activity radiometals. The benchmarks for this grant as originally listed are as follows:

Year 1: The following benchmarks were achieved: (1) pre-doctoral and postdoctoral trainees were selected; (2) Ph.D. dissertation committees were selected; (3) a syllabus for the new class entitled “*Isotopes in Plant Science*” was approved and taught for one semester; and (4) a hot cell and a ^{18}F -synthesis module were purchased and installed.

Year 2: The following benchmarks were achieved: (1) synthesis of first generation radiolabeled targets were completed and initial proof of principle experiments were completed; (2) some internships at Brookhaven National Laboratory were initiated during this period; (3) set-up and training on the Fujifilm bio-imaging system and radiometabolite HPLC were accomplished.

Year 3: The following benchmarks were achieved: (1) internships at BNL were completed; (2) all pre-doctoral students defended their dissertations; (3) installation was completed of the LC/MS for use with radiolabeled samples.

Interdisciplinary Team

The primary collaborators in this program include the following faculty from a variety of departments at the University of Missouri:

Department of Biochemistry: Tom Quinn, Frank Schmidt

Department of Chemistry: Timothy Glass, Michael Harmata, Silvia Jurisson, Susan Lever, J. David Robertson

Division of Biological Sciences: Paula McSteen, David Braun

Division of Plant Sciences: Walter Gassmann, David Mendoza-Coszatl, Henry Nguyen, Jack Schultz, Gary Stacey

Department of Internal Medicine: Tim Hoffman

Department of Radiology: John Lever, C. Jeff Smith

Department of Veterinary Medicine and Surgery: Michael Lewis

University of Missouri Research Reactor (MURR): Cathy Cutler, Alan Ketrin

Plant Imaging Group Meetings were initially held monthly to bimonthly and allowed the various investigators to present their research and discuss research issues and successes. This moved into smaller group meetings that were held as projects became more defined, with the larger group meetings held less frequently.

Graduate Course Development

The graduate level course *Isotopes in Plant Science* (Chem 8085) was developed by Professor Susan Lever.

Graduate Student Trainees who worked on this Grant (not all supported by it)

Rui Sun, Ph.D. December 2011; J. David Robertson, mentor; current position analytical chemist for a contract laboratory in Los Angeles, CA specializing in pharmacy and biochemistry.

Abigail Ferrieri, Plant Sciences Ph.D. 2012; Jack Schultz, mentor; currently postdoctoral fellow at the Max Planck Institute for Chemical Ecology, Jena, Germany.

Patrick Cavins, Chemistry Ph.D. 2015; Tim Glass, mentor; currently postdoctoral fellow with Prof. Susan Lever (Chemistry, University of Missouri-Columbia)

Lihui Song, Chemistry Ph.D. 2013; Silvia Jurisson, mentor; Gary Stacey and Minviluz Stacey, co-mentors

Xingyao Wang, 5th year Chemistry Ph.D. candidate; Susan Lever, mentor

Tom Brossard, Chemistry Ph.D. 2015; J. David Robertson, mentor; funded by grant; currently postdoctoral fellow, Argonne National Laboratory, Chicago, IL.

Dustin Demoin, Chemistry Ph.D. 2014; Silvia Jurisson, mentor; just completed postdoctoral fellowship at Memorial Sloan Kettering Cancer Center, NY.

Carissa Hampton, Chemistry Ph.D. 2015; Michael Harmata, mentor; currently postdoctoral fellow, St. Louis University, St. Louis, MO.

Ashley Dame, Chemistry Ph.D. candidate; Silvia Jurisson, mentor
Nga Thuyen, Plant Sciences, Ph.D. candidate; David Mendoza-Cozatl, mentor
Thu Tran, Biological Sciences, Ph.D. candidate; David Braun, mentor

Postdoctoral Fellows who worked on this Grant

Vikram Gaddam, Ph.D., completed post-doctoral fellowship September 2012; current position organic chemist in India.

Xuefeng Gao, Ph.D., post-doctoral fellow; Michael Harmata, mentor; currently Washington University, St. Louis, MO.

Weijiang Yang, Ph.D., post-doctoral fellow; Michael Harmata, mentor; Silvia Jurisson, co-mentor; currently post-doctoral fellow, University of Michigan, Ann Arbor, MI.

David Rotsch, Ph.D., post-doctoral fellow; Silvia Jurisson, mentor; Cathy Cutler, co-mentor; currently Staff Scientist, Argonne National Laboratory, Chicago, IL.

Publications (trainees in bold Italics)

H.J.R. Popham, **R. Sun**, K.S. Shelby, J.D. Robertson, "Iron Levels Change in Larval *Heliothis virescens* Tissues Following Baculovirus Infection," *Biological Trace Element Research*, **2012**, 148(3), 356-362; DOI 10.1007/s12011-012-9373-1.

H.J.R. Popham, **R. Sun**, K.S. Shelby, J.D. Robertson, "Changes in Trace Metals in Hemolymph of Baculovirus Infected Noctuid Larvae," *Biological Trace Element Research*, **2012**, 146(3), 325-334 ; DOI 10.1007/s12011-011-9257-9.

T.A. Coudron, L.C. Mitchell, **R. Sun**, J.D. Robertson, N.V. Pham, H.J.R. Popham, Dietary Composition Affects Levels of Trace Metals in the Predator *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae), *Biological Control*, **2012**, 61, 141-146; DOI 10.1016/j.biocontrol.2012.01.0.

A.P. Ferrieri, H. Appel, R.A. Ferrieri, J.C. Schultz, Novel application of 1-[¹⁸F]fluoro-2-deoxy-d-glucose to study plant defenses, *Nuclear Medicine and Biology*, **2012**, 39(8), 1152-1160; DOI 10.1016/j.nucmedbio.2012.06.005.

A.P. Ferrieri, B. Agtuca, H. M. Appel, R. A. Ferrieri, J. C. Schultz, Temporal changes in allocation and partitioning of new carbon as ¹¹C elicited by simulated herbivory suggest that roots shape aboveground responses in *Arabidopsis*, *Plant Physiology*, **2013**, 161(2), 692-704; DOI 10.1104/pp.112.208868.

V. Gaddam, M. Harmata, "Synthesis of 6'-deoxy-6'-fluorosucrose," *Carbohydrate Research*, **2013**, 369, 38-41.

W. Ying, V. Gaddam, M. Harmata, "Chemical Synthesis of 1'-Deoxy-1'-fluorosucrose," *Organic Letters*, **2013**, 15, 2723-2725; DOI 10.1021/ol401044h.

A.P. Ferrieri, B. Agtuca, H. Appel, R.A. Ferrieri, J.C. Schultz, "Getting to the root of the problem: methyl jasmonate induces temporal changes in carbon transport and partitioning in *Arabidopsis thaliana* that depend on root-shoot signaling," *Plant Physiol.*, **2013**, 161, 692-704.

X. Gao, V. Gaddam, M. Harmata, "A Synthesis of 6-Deoxy-6-Fluorosucrose Suitable for PET Applications," *Carbohydrate Research* **2014**, 400, 14-18.

D. G. Mendoza-Cozatl, Q. Xie, G. Z. Akmakjian, T. O. Jobe, A. Patel, M. G. Stacey, **L. Song, D. W. Demoin**, S. S. Jurisson, G. Stacey, J. I. Schroeder, “OPT3 is a component of the iron-signaling network between leaves and roots and misregulation of *OPT3* leads to an over-accumulation of cadmium in seeds,” *Molecular Plant* **2014**, 7,1455-69; DOI:10.1093/mp/ssu067.

B. Agtuca, E. Rieger, K. Hilger, **L. Song**, C. Robert, M. Erb, A. Karve, R.A. Ferrieri “Carbon-11 reveals opposing roles of auxin and salicylate in regulating leaf physiology, leaf metabolism and resource allocation patterns that impact root growth in *Zea mays*,” *J Plant Growth Regulation*, **2014**, 33, 328-339.

V.C.S. Pankievicz, F.P. Amaral , K.F.D. Santos, B. Agtuca, Y. Xu, M.J. Schueller, A.C.M. Arisi, M.B.R. Steffens, E.M. de Souza, F.O. Pedrosa, G. Stacey, R.A. Ferrieri ‘Robust biological nitrogen fixation in a model grass-bacterial association,’ *The Plant Journal* **2015**, 81, 907-919.

D. Rotsch, T. Brossard, S. Bihmidine, **W. Ying, V. Gaddam**, M. Harmata, J. D. Robertson, M. Swyers, S. Jurisson, and D. M. Braun, “Radiosynthesis of 6'-deoxy-6'[¹⁸F]fluorosucrose via Automated Synthesis and its Utility to Study *in vivo* Sucrose Transport in maize *Zea mays* Leaf,” *PLOS ONE* **2015**, 10(5): e0128989. doi:10.1371/journal.pone.0128989.

Dissertations

Rui Sun (PhD **2011**, Chemistry, Advisor: JD Robertson), “Measurement of Trace Element Levels in Noctuid Larvae in Response to Baculovirus Infections

Abigail Ferrieri (PhD **2012**, Plant Biology and Genetics, Advisor: J Schultz), Source-sink interactions shape herbivore-induced defense responses in *Arabidopsis thaliana*

Lihui Song (PhD **2013**, Chemistry, Advisors: S Jurisson and G Stacey), Applications of Radiotracers in Plant Biology

Dustin Demoin (PhD **2014**, Chemistry, Advisors: S Jurisson, C Deakyne and T Hoffman), Utilizing an Experimental and Computational Approach to Ligand Design for Chelatin Oxorhenium(V) and Oxotechnetium(V)

Patrick Cavins (PhD **2015**, Chemistry, Advisor: T. Glass), Fluorine-18 Capture by substituted BODIPY Derviatives

Tom Brossard (PhD **2015**, Chemistry, Advisor: JD Robertson), Cyclotron Produced Nuclides for PET Imaging and Radiotracer Studies

Carissa Hampton (PhD **2015**, Chemistry, Advisor: M Harmata), I. [2,3]-Sigma Tropic Rearrangement of Propargylic Sulfinates, II. Regiodivergent Synthesis of 1- and 2-Arylsulfonyl 1,3-Dienes, and III. Synthesis of Tröger's Base-Derived Ligands

Coffman, Clayton (PhD **2016**, Plant Biology and Genetics, Advisors: J Schultz and H Appel), Far-red light influence on carbon allocation in *Arabidopsis*

Presentations and Posters at Meetings (presenter underlined; trainees in bold Italics)

R. Sun, H.J.R. Popham, K.S. Shelby, and J.D. Robertson, "Measurement of trace elements during the development and immune response of *Heliothis virescens* larvae," presented at the 240th National Meeting of the American Chemical Society, Boston, MA, August 22-26, **2010**.

S. S. Jurisson, S. Z. Lever, J. D. Robertson, R. Ferrieri, C. Cutler, T. Glass, M. Harmata, T. Quinn, ***L. Song, P. Cavins, R. Sun***, "Training for the development of novel radiotracers for interrogations of biological systems", presented at the 240th ACS National Meeting, 22-26 August **2010**, Boston, MA.

S. S. Jurisson, S. Z. Lever, J. D. Robertson, R. Ferrieri, C. Cutler, T. Glass, M. Harmata, T. Quinn, ***L. Song, P. Cavins, R. Sun***, "Training for the development of novel radiotracers for interrogations of biological systems", presented at the 240th ACS National Meeting, 22-26 August **2010**, Boston, MA.

A.P. Ferrieri, H. Appel, B. Babst, R. Ferrieri, J. Schultz "Defense-induction elicited by methyl-jasmonate in *Arabidopsis thaliana* alters 2-[¹⁸F]fluoro-2-deoxy-D-glucose allocation and use in phenolic glycoside biosynthesis" April 18-23, **2011** University of Missouri Life Sciences Week (Poster Presentation, 1st Place in Research Competition for Genetics, Evolution, and Environment Category).

Song, L., Stacey, M. G., Jurisson, S. S., Stacey, G. "Study of the heavy metal accumulation and the biological function of AtOPT3 in *Arabidopsis thaliana*", accepted for oral presentation at Plant Biology 2011, Minneapolis, MN, 6-10 August **2011**.

V. Gaddam, M. Harmata, "Synthesis of 6'-Deoxy-6'-fluorosucrose," presented at the 25th Annual Organic Chemistry Day, University of Missouri-Columbia, April 21, **2012**.

S. Jurisson, "Radiochemistry adventures: Medical, environmental and biological applications of radiotracers" (Glenn T. Seaborg Award Address for Nuclear Chemistry), presented at the 243rd American Chemical National Meeting, San Diego, CA, 25-29 March **2012**.

Cavins, P.; Zhang, X.; Gabbai, F.; Quinn, T.; Glass, T. "Development of Dual Mode (PET/Fluorescence) Tag for Monitoring Plant-Signaling Peptides" 243rd National American Chemical Society Meeting, San Diego, California, March **2012**

L. Song, S. S. Jurisson, G. Stacey, M. Stacey, R. Ferrieri, "Applications of radioisotopes in *Arabidopsis thaliana*", presented at the 244th American Chemical Society National Meeting, Philadelphia, PA, 19-23 August **2012**.

Cavins, P.; Zhang, X.; Gabbai, F.; Quinn, T.; Glass, T. "Development of Dual Modality (PET/Fluorescence) BODIPY Tag for Peptide Bioconjugation" Young Researchers Symposium of Brookhaven National Lab, Upton, New York, September **2012**

Song, L., Stacey, M.G., Stacey, G., Ferrieri, R.A., Jurisson, S.S. "Applications of Radioisotopes in *Arabidopsis thaliana*—a study case on phytoremediation", presented at the 244th National Meeting of the American Chemical Society, Philadelphia, PA, August **2013**.

T. Brossard, D. Rotsch, V. Gaddam, M. Harmata, C. Cutler, J.D. Robertson, D. Braun, "Automated ¹⁸F labeling of sucrose for transporter studies in Plants via PET", presented at the 245th National Meeting of the American Chemical Society, New Orleans, LA, 7-11 April **2013**.

D. Rotsch, T. Brossard, V. Gaddam, M. Harmata, C. Cutler, J.D. Robertson, S.S. Jurisson, D. Braun, "Automated ¹⁸F Labeling of Sucrose for Transporter Studies in plants via PET", presented at the International Symposium on Radiopharmaceutical Sciences (ISRS2013), Jeju, South Korea, 12-17 May **2013**.

Wang X, Brockman J, Guthrie J, Durback A, Ladd R, Robertson JD, McSteen P, Lever SZ. Neutron Capture Radiography (NCR) of boron distribution in maize. Presented at the 248th American Chemical Society National Meeting, August 10-14, 2014, San Francisco, CA.

W. Ying, M. Harmata, "Chemical Synthesis Of 1'-Deoxy-1'-fluorosucrose," presented at the 246th National Meeting of the American Chemical Society, Indianapolis, September 8-12, **2013**.

W. Ying, M. Harmata, "Chemical Synthesis of 1'-Deoxy-1'-Fluorosucrose," presented at the 26th Annual Organic Chemistry Day, University of Missouri-Columbia, April 27, **2013**.

T. Brossard, W. Ying, D. Rotsch, V. Gaddam, M. Harmata, S. Jurisson, J. D. Robertson, D. Braun "Automated F-18 Labeling of Sucrose for Transporter Studies in Plants via PET," presented at the 30th Annual Missouri Life Sciences Week, University of Missouri-Columbia, April 14, **2014**.

W. Ying, M. Harmata, "Chemical Synthesis of 4-Fluoroglutathione," presented at the 27th Annual Organic Chemistry Day, University of Missouri-Columbia, April 12, **2014**.

D. G. Mendoza-Cozatl, "Long-distance transport and seed loading of nutrients and toxic metals," presented at the 1st International Workshop on Engineered Crops, Des Moines, IA, April **2014** (invited).

D. G. Mendoza-Cozatl, "Long-distance transport and seed loading of essential and toxic metals," presented at the Soil-Water-Plant Summit, Tyson Research Center, St. Louis, MO, April **2014** (invited).

Cavins, P.; Zhang, X.; Mathes, Z.; Cutler, C.; Quinn, T.; Glass, T. "Boron-substituted BODIPY and their potential application as new dual modality (PET/Fluorescence) peptide bioconjugates" *248th National American Chemical Society Meeting*, San Francisco, California, August **2014**

Cavins, P.; Zhang, X.; Mathes, Z.; Cutler, C.; Quinn, T.; Glass, T. "Photoactive Boronsubstituted BODIPYs and their use as dual modality (PET/Fluorescence) peptide bioconjugates" *Midwest Regional American Chemical Society Meeting*, Columbia, Missouri, October **2014**

S. S. Jurisson, "Radiotracers for biological, environmental, and medical applications", presented at the 249th American Chemical Society National Meeting, 22-26 March **2015**, Denver, CO (invited).

Zhang, S.; Cavins, P.; Akurathi, V.; Glass, T.; Packard, B. "Photoactivated F-18 Fluorination on a Novel BODIPY Derivative" *21st International Symposium on Radiopharmaceutical Sciences*, Columbia, Missouri, May **2015**

D. G Mendoza-Cozatl, "Molecular mechanisms of phloem transport and seed loading of trace metals", presented at the 5th Joint Symposium MU-Gyeongsang National University, South Korea, October **2015** (invited).

D. G Mendoza-Cozatl, "Phloem transport of trace metals in *Arabidopsis*," presented at the 26th International Conference on *Arabidopsis* Research, Paris, France, July **2015** (invited).

D. G. Mendoza-Cozatl, "Long-distance transport of nutrients and toxic metals," presented at the 5th Pan American Plant Membrane Biology Workshop, San Pedro de Atacama, Chile, June **2015** (invited).

D. G. Mendoza-Cozatl, "Molecular mechanisms of phloem transport and seed loading of heavy metals", presented at the 1st UWC-MU Plant Science Symposium, Cape Town, South Africa, June **2015** (invited).

C. Hampton, T. Brossard, D. Rotsch, W. Ying, V. Gaddam, M. Harmata, J. D. Robertson, M. Swyers, S. Jurisson, D. M. Braun, "Radiosynthesis of Deoxyfluorosucrose Analogs and Their *in Vivo* Study of Sucrose Transport in Maize Leaves," presented at Pacifichem 2015, Honolulu, December 15-20, **2015**.

C. S. Hampton, T. Tran, T. Brossard, M. Harmata, J. D. Robertson, S. Jurisson and D. M. Braun, "Radiosynthesis of Deoxyfluorosucrose Analogs and their *in vivo* Study of Sucrose Transport in Maize Leaves," presented at Life Sciences Week 2016 Poster Session, University of Missouri-Columbia, April 18, **2016**.

Cavins, P.; Lever, S. "Preparation of Isotopically Labelled Ascorbic Acid Precursors to Better Understand Ascorbic Acid Biosynthesis *in planta* and *in vitro*" *NSF EPSoR Plant Imaging Consortium Meeting* Fayetteville, Arkansas, July 2016

Invited Faculty Seminars at Other Institutions

D. G. Mendoza-Cozatl, Seminar series, Chemistry and Physics, Arkansas State University, Jonesboro, March, 2016.

D. G. Mendoza-Cozatl, Seminar series, Soil and Crop Sciences, Cornell University, Ithaca, September, 2015.

D. G. Mendoza-Cozatl, Seminar series, Centro de Ciencias Genomicas, Mexico, April 2015.

Poster Presentations at the DOE Grantees Meeting on 5-6 April 2011

P. L. Cavins, T. E. Glass, X. Zhang, T. P. Quinn, F. Gabbai, "Development of Dual Mode Tags (Fluorescence/PET) for Monitoring Extracellular Plant Signaling Peptides"

A. Ferrieri, H. Appel, B. A. Babst, J. Schultz, R. A. Ferrieri, "Non-Medical Uses of 2-[F-18]Fluoro-2-Deoxy-D-Glucose to Study Defense-Induced Carbon Allocation in Plants"

L. Song, M. G. Stacey, G. Stacey, S. S. Jurisson, "Study of the Biological Function of the AtOPT3 Transporter and Heavy Metal Accumulation in *Arabidopsis thaliana*"

R. Sun, H. J. R. Popham, K. S. Shelby, J. D. Robertson, "Measurement of Trace Elements of Larvae During Normal Development and in Response to Baculovirus Infection"

Manuscripts in Preparation

L. Song, M.G. Stacey, G. Stacey, S.S. Jurisson, Heavy metal accumulation in opt3-2 Arabidopsis mutant.

L. Song, D.W. Demoin, B. Agtuca, R.A. Ferrieri, M.G. Stacey, G. Stacey, S.S. Jurisson, A study of Fe homeostasis and carbon metabolism in Arabidopsis.

L. Song, B. Agtuca, R.A. Ferrieri, M.G. Stacey, G. Stacey, S.S. Jurisson, The use of $^{11}\text{CO}_2$ to investigate the dynamics of sugar metabolism and re-location in Arabidopsis starch mutants.

L. Song, B. Agtuca, M. J. Schueller, S. S. Jurisson, G. Stacey, R. A. Ferrieri Relationship between carbon mobilization and root growth measured by carbon-11 tracer in Arabidopsis starch mutants.

X. Wang, J. Brockman, J. Guthrie, J.D. Robertson, S.Z. Lever Imaging boron distribution in plant tissues by Quantitative Neutron Capture Radiography.

T. Brossard, C. Hampton, T. Tran, M. Harmata, J. D. Robertson, S. S. Jurisson, D. Braun, Synthesis, validation, and transport of ^{18}F -labeled 1- and 6-sucrose.

P. Cavins, S. Zhang, V. Akurathi, A. Packard, T. Glass, Photoactivated F-18 Fluorination on a Novel BODIPY Derivative.

Internships at BNL

Three graduate student trainees (**Abigail Ferrieri**, **Lihui Song** and **Patrick Cavins**) spent several months at BNL working with Dr. Rich Ferrieri to further their projects using the novel radiochemistry capabilities available at BNL (e.g., access to ^{11}C).

Equipment Purchases by this Grant

(1) GE Typhoon FLA 9000 plus associated software, etc.; purchased in 2010 for \$121,846.15.

(2) Eckert and Ziegler Modular Lab; purchased in 2011 for \$235,459.50; located at MURR.

(3) Von Gahlen Shielding Box Model DCE 1740; purchased 10/2011 for \$73,200.00.

(4) TASL System for Neutron Dosimetry; purchased 10/01/2013 for \$90,500.

(5) Capintec Dose Calibrator CRC-55TW, purchased 07/2013 for \$9,373.00.

(6) \$10,000 was put toward the purchase of an LCQ Fleet LC/MS System from ThermoFisher Scientific, purchased 03/2013 for \$79,456.00.

(6) \$5,000.00 was put toward the purchase of a CEM Corporation Microwave Unit, purchased on 5/2016 for \$20,392.00.

All of these systems continue to be used for projects supported by the grant and their continuation, as well as other radiochemistry projects carried out by various researchers in plant biology, chemistry, etc.

Other

The data/knowledge generated from the DOE grant was leveraged to secure an NSF EPSCoR Track II award, and we are using ¹⁸F-fluorosucrose to study how plants modify carbohydrate partitioning in response to heat stress.

Dr. Richard Ferrieri and Dr. Michael Schueller moved from Brookhaven National Laboratory to the University of Missouri Research Reactor Center (MURR) in July 2016. This move was part of a \$3M investment by the University of Missouri into setting up a Plant Imaging Laboratory at MURR.