

# 10th Annual Course Isotope Tracers in Metabolic Research: Principles and Practice of Kinetic Analysis

---

October 30-November 3, 2017

Homewood Suites by Hilton® Nashville Vanderbilt

2400 West End Avenue

Nashville, Tennessee 37203 (also where the course takes place)

615-340-8000

## FACULTY

Henri Brunengraber, Case Western Reserve U. **Course Co-Director**

Gary Cline, Yale U.

Melanie Cree Green, U. of Colorado

Joanne Kelleher, Mass. Inst. Tech.

Maren Laughlin, National Inst. Health

Owen McGuinness, Vanderbilt U. **Course Co-Director**

Matthew Merritt, U. of Florida

Elizabeth Parks, U. of Missouri

Stephen Previs, Merck

Michelle Puchowicz, Case Western Reserve U.

Jamey Young, Vanderbilt U.

Robert R. Wolfe, U. Arkansas **Course Co-Director**

## General Information

### Hotel Information and Food and Registration

Check in time for the hotel is 3:00, if you need to be there earlier notify the hotel. The hotel will provide a full hot breakfast and in the evening a light dinner with complementary social hour each day in the lobby. The course will provide lunch each day as well as snacks and drinks during the break periods. On Wednesday night all course participants are welcome to come to the Wild Horse Saloon ([www.wildhorsesaloon.com](http://www.wildhorsesaloon.com)) for dinner and dancing (6:30-8:30). Buses will be provided to take participants to the event and return you to the hotel. There are plenty of restaurants within walking distance of the hotel. Downtown Nashville is approximately 2 miles from the hotel. The course will end Friday at 11:00 am to allow time for participants to make early afternoon flights.

To make **hotel reservations** call 1 (615) 320-7772 and mention the identifier:

10th Annual Tracer Course + Dates of course

or go directly to the following link

<http://homewoodsuites.hilton.com/en/hw/groups/personalized/B/BNAVBHW-VTC-20171029/index.jhtml>

Please book by September 30<sup>th</sup> to get course discount room rates

Cost for registration:

Academic Faculty (\$800 USD)

Industry Scientist (\$1,300 USD)

Postdoctoral/Student (\$400 USD)

The link to **course registration** is below. Credit cards are accepted.

<https://is.gd/tracercourse2017>

### COURSE FORMAT

The course and homework problems will be run on paperless format. Participants are expected to come with a laptop computer equipped with Excel and a wireless Internet connection. All course material (including slides and problem sets) will be available for download a few days before the course starts. **Registered participants will receive the link and password by email on Friday, October 27, 2017.** Feel free to print the downloaded material. The faculty will systematically upload any new or additional material (including problems' solutions) on the course webpage. Note that, in order to foster intellectual exchanges without fear of plagiarism, this course will have a closed meeting format, just like a Gordon Conference.

### PRESENTATIONS by PARTICIPANTS

There will be trainee presentations on the evening of Thursday, November 2, 2017. Specifically, 10 participants will have the opportunity to outline their research project (planned or ongoing) involving isotopic tracers. We thus invite you to prepare a 7-8 minute slide presentation, which will summarize your project, emphasizing the protocols that use isotopes, the quantitative data you expect to obtain, and any questions you have on the validity of protocols and data interpretation. Each presentation will be followed by comments from the faculty and attendees.

**Please notify Dr. Owen McGuinness ([owen.mcguinness@vanderbilt.edu](mailto:owen.mcguinness@vanderbilt.edu)) by October 30** if you wish to make such a presentation (please let us know the title of your presentation). If your presentation is not selected for the Thursday evening session, you will have an opportunity to present it later to a selected faculty member (see below).

### ONE-ON-ONE MENTORING

## Preliminary program 6.1.17

Participants are also invited to set up 30-minute One-on-One Mentoring/Discussion Sessions with any course faculty. Starting October 30 (1st day of the class), you will be able to set up appointments with course faculty. The scheduling process will be discussed in more detail in an upcoming email.

## Course Schedule

Monday	Morning	Start time: 07:30am
	<p><b>A. 7:30 Registration</b></p> <p><b>B. 8:30 WELCOME</b> (Dr. Maren Laughlin, senior advisor / NIDDK, NIH)</p> <p><b>C. 8:40 PRINCIPLES OF METABOLIC FLUX AND USE OF RADIOACTIVE ISOTOPES</b> (O. McGuinness)</p> <p><u>LEARNING OBJECTIVES</u> &gt; <b>(1)</b> What is metabolic flux and how can tracer dilution principles be used to quantify flux? <b>(2)</b> Responsible Conduct of Research in the use of radioactive isotopes. <b>(3)</b> How does one optimize the measurement of radioactivity of compounds labeled with <math>^{14}\text{C}</math>, <math>^3\text{H}</math> or <math>^{32}\text{P}</math>? <b>(4)</b> How does one measure a metabolic rate using <math>^{13}\text{C}</math> or <math>^3\text{H}</math> tracers? <b>(5)</b> What are the difficulties and limitations of the use of radioactive isotopes to measure metabolic rates?</p> <p><u>SECTIONS</u> &gt; <b>(A) Basic Principles of Metabolic flux</b> (define tracer methodology and principle of isotope dilution). <b>(B) Measurement of beta radioactivity by scintillation counting</b> (Conversion of cpm to dpm (external standards, automatic quench correction, internal standards); How does one deal with counting artifacts (quenching, chemiluminescence)). <b>(C) Principles of measurement of metabolic rates</b> (Notion of specific activity of labeled precursor; Problems and solutions with variations of specific activity of precursor (how does one avoid dealing with one equation and two variables). <b>(D) Limitations of the use of isotopes for metabolic studies</b> (Difference between transfer of label and net flux; Isotopic exchanges; Isotopic equilibration without or with ATP consumption).</p> <p><b>D. 9:50 BREAK</b></p> <p><b>E. 10:10-10:45 PROBLEM BREAKOUT</b>&gt; Four numerical problems of increasing complexity are presented to the attendees to teach them how to plan real-life experiments with radioactive isotopes without guessing the amount of radioactivity to be used. The attendees are given ~30 min to find the solutions. Then, the instructor and the attendees discuss how they went about working on the problems.</p> <p><b>F. 10:45-11:30 Problem Discussion</b></p>	
Monday	Afternoon	Start time: 01:30pm
	<p><b>A. 1:30-3:00 BASIC CONCEPTS IN MASS SPECTROMETRY</b> (R. WOLFE)</p> <p><u>LEARNING OBJECTIVES</u> &gt; <b>(1)</b> gain an understanding of the main mass spectrometry techniques used to investigate metabolic processes with stable isotopes. <b>(2)</b> Become familiar with current expressions of isotopic enrichment, including Tracer:Tracee Ratio and atom (or mol) percent excess. <b>(3)</b> Learn how to measure isotopic enrichment by mass spectrometry (basic approaches). <b>(4)</b> Learn how to calculate isotopic enrichment using Gas Chromatography-Mass Spectrometry and LC-MS/MS.</p> <p><u>SECTIONS</u> &gt; <b>(A) Basic Description of Instrumentation:</b> Isotope ratio mass spectrometry (IRMS); Gas Chromatography-Mass Spectrometry (GC-MS); Gas Chromatography-Combustion-Isotope Ratio Mass Spectrometry (GC-C-IRMS); Liquid Chromatography-Mass Spectrometry (LC-MS; LC-MS/MS). <b>(B) Calculation of Enrichment with IRMS:</b> Correction of enrichment for background enrichment – Tracer:Tracee Ratio (TTR) vs. Molar Percent Enrichment (MPE); skew correction factor to correct for the fact that the natural distribution of mass isotopomers is the same in the sample and the background; <b>d)</b> Use of a standard to calculate enrichment; measurement of <math>^{13}\text{C}</math>-enrichment after combustion; effect of sample size on observed ratio. <b>(C) Calculation of Enrichment with GC-MS</b> (definition of total ion chromatogram, mass spectrum, and selected ion monitoring (SIM); identifying appropriate fragment(s) to monitor; calculation of theoretical abundance; calculation of isotopic enrichment using SIM; effect of skewed abundance of tracer, skew correction factor; overlapping spectra correction, calculation of TTR when TTR &gt; 1 (using multiple ions to calculate isotopic enrichment, using less abundant masses to measure low levels of enrichment, calculation of concentration by internal standard technique).</p> <p><b>B. 3:00-3:15 BREAK</b></p> <p><b>C. 3:15-3:50 HOMEWORK BREAKOUT</b> &gt; Students are asked to calculate isotopic enrichment from GC-MS data</p> <p><b>D. 3:50-4:20 Problem Discussion</b></p>	
Monday	Evening	
	<p>“Free time to explore Nashville”</p>	

Tuesday	Morning	Start time: 09:00am
<b>A. 9:00-10:30 MEASUREMENT OF METABOLIC FLUXES WITH ISOTOPIC TRACERS (R. WOLFE)</b>		
<u>LEARNING OBJECTIVES</u> > (1) Responsible Conduct of Research in human and animal investigations. (2) Gain a conceptual and practical understanding of calculating the rate of substrate appearance (Ra) by tracer dilution using a single pool model with radioactive and stable isotopes. (3) Understand the benefit of priming the substrate pool, how to calculate a tracer priming dose, and the limitations of the primed-constant infusion technique. (4) Understand the basic approach for calculating substrate oxidation using a metabolic tracer. (5) Understand the calculation of fractional synthetic rate.		
<u>SECTIONS</u> > (A) <b>Tracer Kinetics-Single Pool Models</b> (Constant infusion of tracer; Influence of changes in uptake on calculation of rate of appearance; Calculation of Ra with a bolus injection of tracer; Priming the pool; Estimation of Ra in the non-steady state; Minimizing errors by curve fitting). (B) <b>Incorporation Studies</b> (Principles and calculation of substrate oxidation at the whole body level using tracers, including use of Atom Percent Excess vs. Tracer:Tracee Ratio; Bicarbonate recovery factor; Improving the estimation of true precursor enrichment; Priming the bicarbonate pool; Determination of carbon dioxide production with labeled bicarbonate; Problems in determining oxidation with tracers; Labeled CO <sub>2</sub> reincorporation; Contribution of naturally occurring <sup>13</sup> C to apparent CO <sub>2</sub> enrichment; Fractional synthetic rate; Synthetic rate). (C) <b>Non steady-state kinetics.</b> (Single and multiple pool models).		
<b>B. 10:30-10:45 Break</b>		
<b>C. 10:45-11:45 GLUCOSE KINETICS / INCLUDING THE EUGLYCEMIC CLAMP (O. MCGUINNESS)</b>		
<u>LEARNING OBJECTIVES</u> > (1) Responsible Conduct of Research in such types of investigations in rodents and humans. (2) Define the physiological correlates of glucose flux. (3) Learn best practices for experimental design optimization and data interpretation to evaluate insulin action.		
<u>SECTIONS</u> > (A) <b>Overview of Glucose Kinetics</b> (Define steady state; Define the relationship between glucose concentration and glucose mass in the body; Identify sites and relative rates of glucose production and consumption and how these rates differ among species). (B) <b>What Are The Sources of Glucose Appearance?</b> (Understand what 'production' is, from a tissue point of view; define the relative contribution of the liver and kidney to glucose production). (C) <b>How Do We Get Started?</b> (Choosing a tracer; understand how the sites of sampling and infusion can influence the measured rates of glucose flux; know how to optimize the study design to maximize steady state conditions). (D) <b>Assessing Insulin Action</b> (Choosing a tracer; Know how fasting status influences insulin action differently in mice and humans; Define what insulin action is in the liver and the periphery; Understand what a euglycemic hyperinsulinemic clamp is and how to deal with variable rates of endogenous insulin and glucagon secretion; How to recognize and deal with tracer/model assumption errors (non steady-state and negative endogenous production rates); Be able to evaluate data used to calculate hepatic and peripheral insulin action; Understand the principles used in assessing tissue specific glucose uptake).		

Tuesday	Afternoon	Start time: 01:30pm
<b>A. 1:30-2:30 Assessing glucose flux and insulin action using isotopic tracers in the Human (M. CREE GREEN)</b>		
<u>LEARNING OBJECTIVES</u> > (1) Understand how to translate a physiologic hypothesis that insulin action is altered to a tracer study to quantify the site and magnitude of the defect. (2) Understand the experimental protocol(s) followed to evaluate insulin action (3) Understand how to control for patient population variables that impact outcomes.		
<u>SECTIONS</u> > (A) <b>Why is glucose homeostasis altered?</b> (Insulin action vs Insulin secretion vs insulin independent glucose action. (B) <b>Glucose tolerance and insulin secretion:</b> oral vs intravenous glucose delivery. (C) <b>The experimental protocol to quantify insulin action:</b> Hyperinsulinemic euglycemic clamp and limb clamps. (C) <b>Consideration of disease and environment</b> in the design. (Patient health/disease state, Pre-study preparation: Diet, exercise, medications, fasting/fed states).		
<b>B. 2:30-2:45 Break</b>		
<b>C. 2:45-4:00 LIPID METABOLISM: BASIC KINETICS (E. PARKS)</b>		
<u>LEARNING OBJECTIVES</u> > (1) To understand the principles and limitations of various types of measurements of lipid metabolism using stable isotopes. (2) Recognize that glycerol and fatty acid availability are very sensitive to insulin and other hormones. Fatty acid oxidation and triglyceride metabolism in multiple tissues.		
<u>SECTIONS</u> > (A) <b>Lipolysis and Fatty Acid Release:</b> Their flux rates can be assessed using glycerol fatty acid tracer as well as substrate cycling between triglycerides and fatty acids. (B) <b>Fatty Acid Oxidation</b> (Pathways of fatty acid oxidation; Citric acid cycle exchange reactions; in vivo assessment of CPT activity). (C) <b>Multiple</b>		

**substrate pools contribute to lipoprotein and intracellular triglyceride synthesis;** limitations of various methods for measuring intracellular lipid synthesis.

Tuesday	Evening	Start time: 07:00pm
<b>A. INTRODUCTION TO THE NIH GRANTS PROCESS</b> (M. LAUGHLIN)		
<b>B. INSULIN AND GLUCOSE CLAMP</b> (BREAKOUT SESSIONS)		
a. APPLICATION TO ANIMAL MODELS (O. MCGUINNESS)		
b. APPLICATION TO HUMAN MODELS (M. CREE-GREEN AND R. WOLFE)		

Wednesday	Morning	Start time: 08:30am
<b>A. 8:30-10:00 MEASUREMENTS OF ENERGY EXPENDITURE</b> (S. PREVIS)		
<u>LEARNING OBJECTIVES</u> > <b>(1)</b> Outline different methods for quantifying energy expenditure (or CO <sub>2</sub> production) . <b>(2)</b> Identify the pros/cons for each. <b>(3)</b> Outline the general principle of using “doubly labeled water”, listing important criteria for the experimentalist. <b>(4)</b> Explain the rationale for different data normalization/interpretation.		
<u>SECTIONS</u> > <b>(A) Overview of energy expenditure</b> - Where does “energy” go? <b>How Do I Quantify Tissue-Specific Rates of CO<sub>2</sub> Production?</b> a) Arterio-venous balance is required. b) Single vs. multiple compartments. c) Concerns about mixing/complete perfusion. <b>How do I quantify substrate-specific rates of CO<sub>2</sub> production?</b> a) Measure the production of <sup>13</sup> C-labeled CO <sub>2</sub> . b) Concerns about the recovery of a labeled substrate. <b>How do I quantify total body CO<sub>2</sub> production?</b> a) Direct calorimetry. b) Indirect calorimetry (Direct measurements of gas exchange; indirect measurements of gas exchange (i.e.: “doubly-labeled” water)). <b>How Do I Process the Data and Normalize the Results?</b> Note that all the MMPC centers are currently involved in a NIDDK study on defining rules for standardizing rates of energy expenditure (measured by indirect calorimetry) in C57BL mice of different ages and weights across centers. Analysis of covariance with learning modules is freely available on the MMPC website for all centers to compare their data.		
<b>B. 10:00-10:15 Break</b>		
<b>C. 10:15-11:45 MEASURE SYNTHESIS OF PROTEINS, FATS, STEROLS, GLUCOSE &amp; NUCLEIC ACIDS WITH <sup>2</sup>H<sub>2</sub>O</b> (S. PREVIS)		
<u>LEARNING OBJECTIVES</u> > <b>(1)</b> General equations for calculating rates of synthesis in short-term vs. long-term studies, i.e. those that run over several hours vs. those that run over several days, respectively. <b>(2)</b> Why <sup>2</sup> H <sub>2</sub> O is a unique tracer for measuring the synthesis of various macromolecules. <b>(3)</b> Explain why one requires knowledge of the labeling of specific hydrogen(s) in a product molecule to accurately determine its rate of synthesis. <b>(4)</b> Contrast the pros/cons of using GC-MS vs. NMR to measure the labeling of molecules.		
<u>SECTIONS</u> > <b>What can be done with <sup>2</sup>H<sub>2</sub>O that cannot be done with other tracers?</b> a) Simultaneous tracing of multiple processes. <b>Choice between acute and chronic labeling studies?</b> a) Source(s) of blood glucose (acute). b) Total triglyceride dynamics (acute and chronic). c) Protein synthesis _ acute and chronic: (Single vs. multiple proteins; ii. <sup>2</sup> H <sub>2</sub> O vs. H <sub>2</sub> <sup>18</sup> O). <b>Complementary Approach to Glucose-Insulin Clamping:</b> a) Measurements of flux during metabolic steady state vs. “tolerance” testing.		

Wednesday	Afternoon	Start time: 01:30pm
<b>1:30-2:00 MEASURING SYNTHESIS OF ADENINE NUCLEOTIDES, COENZYME A, NUCLEIC ACIDS</b> (BRUNENGRABER)		
<u>LEARNING OBJECTIVES</u> > <b>(1)</b> Identify problems associated with the use of isotopic tracers for very long experiments (weeks or months). <b>(2)</b> Long-term isotopic experiments occur in an open biological system where unlabeled foodstuffs enter the system continuously. <b>(3)</b> During long-term isotopic experiments, salvaged pathways recycle labeled intermediates into <i>de novo</i> synthesis pathways.		

**2:00 -2:45 Practical applications of Physiological Models using Stable Isotopes I** (Kelleher)

Learning objectives: **(1)** To understand methods for describing isotopes in physiological studies. **(2)** To learn a practical method for solving for isotopic mixtures. **(3)** To understand the role of experimental error in developing and testing models. **(4)** To understand the different methods for solving for rates of synthesis and their limitations. Sections Topics: Describing stable isotope tracers. Solving for tracer contribution to mixtures with simple linear regression. Introduction to Pre-steady state labeling. Solving for the rate of synthesis using nonlinear regression

**2:45-3:00 BREAK**

**3:00-5:00 METHODS IN PROTEIN METABOLISM** (WOLFE)

**LEARNING OBJECTIVES** > (1) Understand how to use of whole body protein turnover techniques. (2) Earn how to calculate the rate of synthesis of individual proteins. (3) Learn how to measure tissue protein and amino acid kinetics using tracers and transorgan balance techniques.

**SECTIONS** > **Whole body protein turnover:** a) Catabolic and anabolic states. b) Energy cost of protein synthesis. c) Stochastic model of whole body protein turnover. d) Comparison of tracers; Isotopic determination of urea production. e) Single amino acid tracer kinetics to calculate whole body protein turnover. **Measurement of Protein FSR:** a) Constant tracer infusion. b) Flooding dose tracer injection. c) Sub-flooding dose tracer injection. **Methods to Estimate Precursor Enrichment for Measurement of FSR:** a) Fractional breakdown rate. b) Constant tracer infusion. c) Bolus injection. **Arterio-Venous Model:** a) Measurement of A-V balance. b) 3-pool and 4-pool models of protein kinetics and amino acid transport. c) Measurement of tissue oxidation rate. d) Technical aspects of performing A-V balance studies from mouse to human.

**Wednesday Evening**

Start time: **07:00pm**

**SOCIAL HOUR / DINNER AT WILD HORSE SALOON**

**Thursday**

**Morning**

Start time: **08:30am**

**USE OF POSITIONAL ISOTOPE ANALYSIS TO ASSESS PATHWAY FLUXES** (G. CLINE, M. MERRITT)

**LEARNING OBJECTIVES** > (1) Understand the basic principles of NMR. (2) Understand how the information content of NMR data differs from MS data. (3) Understand how metabolic flux information is extracted from NMR data. (4) Review common applications of NMR to metabolic flux measurements.

**SECTIONS** >

- A. **8:30-9:15 NMR in Tracer Metabolism** (Merritt): Basic NMR Principles (Measurement of fractional enrichment, spin-spin coupling, multiplet analysis; measuring  $^{13}\text{C}$  and  $^2\text{H}$  isotopomer distribution).
- B. **9:15-10:00 Applications to Biochemical Physiology: Steady State Measurements of Metabolic Fluxes** (Cline): Metabolic pathways in isolated cells (TCA cycle, anaplerosis, and substrate cycling); Calculating hepatic fluxes by multinuclear NMR (glycogen synthesis pathways, gluconeogenesis and glycogenolysis, TCA cycle pathways).
- C. **10:00-10:15 Break**
- D. **10:15-11:10 in vivo Applications: Kinetic Analysis of Metabolic Fluxes (Cline)** - Practical aspects of performing *in vivo* experiments (homogeneity, localization, lipid suppression etc.). b) Conventional  $^{13}\text{C}$  labeling strategies (Brain / Muscle). c) Alternative  $^{13}\text{C}$  labeling strategies (Brain / Liver). d) Complementary *in vivo* techniques
- E. **11:10-12:00 Evolving techniques** (Merritt): a) Hyperpolarization-intracellular fluxes.

**Thursday**

**Afternoon**

Start time: **01:30pm**

**USE OF MASS ISOTOPE DISTRIBUTION ANALYSIS** (KELLEHER, PUCHOWICZ)

**LEARNING OBJECTIVES** > (1) To appreciate the multiple uses of mass isotopomer distribution for metabolic investigation, with the understanding that mass isotopomer distributions and positional isotopomer distributions yields complementary insights on metabolic regulation.

- A. **1:30-2:00 Analytical Applications** (Puchowicz) a) Measurement of low analyte enrichment by oligomerization of analyte. b) Use of hexamethylenetetramine to amplify the  $^2\text{H}$ -enrichment on glucose carbons, which can be converted to formaldehyde; measurement of low  $^2\text{H}$ - or  $^{18}\text{O}$ -enrichment of water. c) Measurement of low  $^2\text{H}$ -enrichment of analytes by isotope fractionation.
- B. **2:00-3:15 Practical applications of Physiological Models using Stable Isotopes II** (Kelleher): Learning objectives: (1) To understand key differences in using stable and radioisotopes. (2) To understand the difference between linear and non-linear models. (3) To understand the complexities of isotope incorporation studies. (4) To develop strategies for identifying and dealing with underdetermined models. Sections: Stable and radioisotopes, which to choose Linear versus nonlinear models, superposition Nonlinear Model for lipid synthesis from  $^{13}\text{C}$  precursors. What to do if the model does not fit the data? Overdetermined and underdetermined models.
- C. **3:15-3:30 Break**
- D. **3:30-5:00 OPTIONAL COMPUTER WORKSHOP**  
**Metabolic Flux Analysis Workshop** (J. Young)> Metabolic Flux Analysis using the MFA Suite of tools with GC-MS data. Investigations of pathway regulation + pathway discovery (metabolomics associated with mass isotopomer distribution).

**Thursday Evening**  
**TRAINEES PRESENTATIONS (10)**

Start time: **07:00pm**

**Friday Morning**

Start time: **08:30pm**

**8:30-9:30 PATHWAY DISCOVERY THROUGH METABOLOMICS ASSOCIATED WITH STABLE ISOTOPE TECHNOLOGIES (H. BRUNENGRABER).**

LEARNING OBJECTIVES > Limitations of non-targeted metabolomics, used as a single research tool, to investigate the regulation of metabolic pathways. Changes in relative concentrations do not reflect changes in flux rates. The association of metabolomics and stable isotope technology allows to follow C, H, N of substrates through the metabolome. This leads to the identification of new pathways and new regulatory mechanisms. Metabolomics should be integrated with classical tools used to investigate metabolism: flux rates, enzyme activity/regulation, balance studies

**9:30-10:30 INHERENTLY DIFFICULT PROBLEMS (H. BRUNENGRABER).**

LEARNING OBJECTIVES > **(1)** Appreciate limitations on the use of isotopes for metabolic studies, using examples of problems, which have challenged investigators for many years. **(2)** Measurement of Cori cycling with labeled lactate. **(3)** Measurement of fatty acid oxidation *in vivo*. **(4)** Measurement of glucose production across a high blood flow organ (kidney, intestine). **(5)** Glyceroneogenesis. **(6)** Ketogenesis vs. pseudoketogenesis. **(7)** Measurement of coenzyme A and nucleic acid turnover with <sup>2</sup>H-enriched water. **(8)** Impacts of secondary tracers on the process investigated (e.g., (i) formation of [<sup>13</sup>C]ketone bodies from infused [<sup>13</sup>C]fatty acids), and (ii) formation of [<sup>13</sup>C]glucose from infused [<sup>13</sup>C]propionate). **(9)** Impact of loads of labeled substrates on metabolic processes being traced.

**11:00** Lunch Boxes will be available for your trip home.