USTUR-0536-19

United States Transuranium and Uranium Registries

Annual Report

April 1, 2018 - March 31, 2019

College of
Pharmacy and
Pharmaceutical Sciences
Washington State University

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Compiled and Edited

Maia Avtandilashvili and Sergei Y. Tolmachev

December 2019

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USTUR

A unique resource since 1968

Learning from Plutonium and Uranium Workers
United States Transuranium and Uranium Registries
College of Pharmacy and Pharmaceutical Sciences
Washington State University 1845 Terminal Drive, Suite
201, Richland, WA 99354

800-375-9317 Toll Free
509-946-6870 Direct
509-946-7972 FAX
www.ustur.wsu.edu

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Faculty and Staff

Faculty

Sergei Y. Tolmachev	Director, Associate Research Professor
Stacey L. McComish	Associate in Research
Maia Avtandilashvili	Assistant Research Professor
George Tabatadze	Assistant Research Professor
Sara Dumit	Ph.D. Candidate

Emeritus and Adjunct Faculty

Ronald L. Kathren	Professor, Emeritus
Daniel J. Strom	Adjunct Professor

Classified Staff

Margo D. Bedell	Program Specialist II
Elizabeth M. Thomas	Laboratory Technician II

Part-time Employees

Warnick Kernan	Laboratory Assistant I
Florencio T. Martinez	Medical Technologist

Consultants

Eric Kiesel	Forensic Pathologist
Minh Pham	IT Support
Mariya Tolmachova	Technical Editor

Student Employees

Samantha Walter	Laboratory Assistant II
Christian Gomez	Laboratory Assistant II

Advisory Committee

Committee Chair

Roger O. McClellan	Toxicology

Committee Members

Heather J. Hoffman	Epidemiology
Timothy J. Ledbetter	Ethics
Thomas L. Rucker	Radiochemistry
Arthur W. Stange	Occupational Health
Luiz Bertelli	Health Physics (*incoming*)

Contact Information

Address

U.S. Transuranium and Uranium Registries
College of Pharmacy and Pharmaceutical Sciences
Washington State University
1845 Terminal Drive, Suite 201
Richland, WA 99354-4959

Phone: 509-946-6870
Toll-Free: 800-375-9317
Fax: 509-946-7972
www.ustur.wsu.edu

E-mail

Sergei Y. Tolmachev	stolmachev@ wsu.edu
Stacey L. McComish	s.mccomish@ wsu.edu
Maia Avtandilashvili	m.avtandilashvili@wsu.edu
George Tabatadze	george.tabatadze@wsu.edu
Elizabeth M. Thomas	elizabeth.thomas@wsu.edu
Margo D. Bedell	margo.bedell@ wsu.edu

Executive Summary

Sergei Y. Tolmachev, *USTUR Director*

This report summarizes organization, activities, and scientific accomplishments for the U.S. Transuranium and Uranium Registries (USTUR) and the associated National Human Radiobiology Tissue Repository (NHRTR) for the period of April 1, 2018 – March 31, 2019. This is the second fiscal year (FY) of the USTUR's 5-year grant proposal (April 1, 2017 – March 31, 2022).

Letter of Commendation

The year 2018 marks the 50th anniversary of the USTUR. On April 23, 2018, the Registries received the letter of commendation from Mr. Matthew Moury, U.S. Department of Energy's (DOE) Associate Under Secretary for Environment, Health, Safety and Security (AU-1). In his letter, Mr. Moury states that the USTUR is the longest-running domestic radiation health study in the United States, highlights recent research, thanks the USTUR team for its dedication to the program, and expresses a deep sense of gratitude for Registrants and their families. The letter is provided in Appendix A.

Funding Increase

The FY2020 grant renewal proposal to manage and operate the USTUR and the associated NHRTR, during April 1, 2019 – March 31, 2020, was submitted to the Department of Energy (DOE) Office of Health and Safety (AU-10). The annual budget increased by ~10%. The approved FY2019 budget amounted to $1,200,000.

Scientific Advisory Committee

The annual meeting of the USTUR's Scientific Advisory Committee (SAC) moved from fall to spring to better align with the USTUR's fiscal year. Thus, the 2018 SAC meeting was held April 26 – 27 in Richland, WA. Dr. Luiz Bertelli (Los Alamos National Laboratory) joined the SAC as a health physics representative.

Ph.D. Research

On May 14, 2018, Sara Dumit (WSU Pharmaceutical Sciences) successfully defended her doctoral dissertation titled "Development of a New Compartmental Model for Plutonium Decorporation".

College Name Changed

On July 1, 2018, College of Pharmacy changed its name to College of Pharmacy and Pharmaceutical Sciences (CPPS).

Organization and Personnel

Sergei Tolmachev was promoted to the rank of Research Professor in the Department of Pharmaceutical Sciences effective July 1, 2019. In FY2019, 6.8 full-time equivalent (FTE) positions, including one adjunct faculty at 0.2 FTE, one graduate student at 0.1 FTE and total of 0.7 FTE for temporary professional workers, were supported by the available funding. The organizational structure of the USTUR Research Center during FY2019 is provided in Appendix B.

Registrant Donations

One whole-body and one partial-body donations were received by the USTUR in FY2019. As of March 31, 2019, the Registries had received 46 whole- and 310 partial-body donations.

NHRTR Inventory

As of March 31, 2019, 9,828 tissue samples from 45 whole-body donations and 113 partial-body donations were inventoried. These Registrants passed away between 1982 and 2018. Additionally, two samples from two living cases (biopsy specimens) were inventoried.

Radiochemistry Operation

Three hundred forty-two tissue samples from two whole-body and 15 partial-body donations were analyzed for plutonium and americium isotopes using α-spectrometry. Radiochemical analyses of 12 partial-body cases were completed.

Health Physics Database

Standardization of exposure records and bioassay data for 15 partial-body cases, including 13 living and two deceased Registrants, was completed. As of March 31, 2019, the database holds 130,378 data records from 214 deceased donors (46 whole-body and 168 partial-body), 31 living Registrants (six whole-body and 25 partial-body), and two special study cases.

Research Results

USTUR faculty authored six and co-authored three papers. These included five papers from the USTUR special issue of the Health Physics journal.

During FY2019, five invited, five podium and four poster presentations at national and international conferences were given by the USTUR faculty and a graduate candidate.

Institutional Review Board

The annual Institutional Review Board (IRB) review was completed and approved by the Central DOE IRB and is valid until September 11, 2019.

Administrative

The annual USTUR Newsletter (USTUR-0510-18) was sent to the Registrants and/or their next-of-kin.

Financial and Administrative Report

Margo D. Bedell, *Program Specialist II*

On March 31, 2019, the USTUR completed the second grant year of the USTUR's 5-year grant proposal (April 1, 2017 – March 31, 2022). Fiscal year (FY) 2019 (April 1, 2018 – March 31, 2019) funding sources were:

Federal Resources

Grant

U.S. Department of Energy Office of Health and Safety, Office of Domestic and International Health Studies (DOE/AU-13):

Manage and Operate the United States Transuranium and Uranium Registries

DE-HS0000073

Amount awarded: $1,100,000
Period: April 1, 2018 – March 31, 2019

Operating budget

With a $8,332 positive carry-over from FY2018, the USTUR net operating budget for FY2019 was $1,108,332. Total operating expenses for FY2019 were $1,103,326 (Fig. 1) resulting in a positive balance of $5,006.

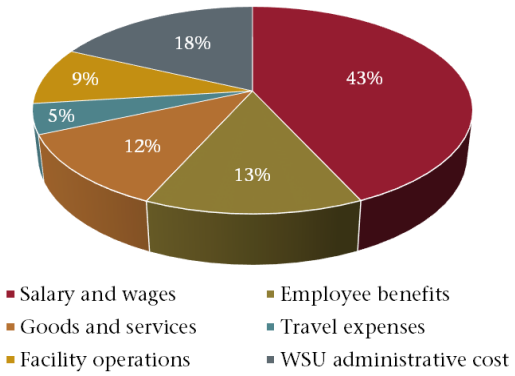


Fig.1. FY2019 operating budget breakdown.

50th Anniversary Funding

U.S. Department of Energy Office of Health and Safety (DOE/AU-10):

USTUR: Five Decade Follow-up of Plutonium and Uranium Workers

Amount awarded: $30,000
Period: October 1, 2016 – September 30, 2018 (one-year no-cost extension)
Available in FY2019: $9,492
FY2019 expenses: $0

Grant Administration

FY2020 Grant Renewal

On February 4, 2019, a grant renewal proposal to manage and operate the United States Transuranium and Uranium Registries and the associated National Human Radiobiology Tissue Repository (NHRTR) during FY2020 (April 1, 2019 – March 31, 2020) was submitted to the DOE/AU-13 through the WSU's Office of Research Support and Operations (ORSO). The requested FY2020 budget was $1,200,000.

Reporting

The FY2018 annual report (USTUR-0501-18) for the DE-HS0000073 grant was published and electronically distributed.

Congratulations, Sara!

Sergei Y. Tolmachev, *Associate Research Professor*

On May 14, 2018, USTUR/WSU College of Pharmacy student, Sara Dumit, successfully defended her doctoral dissertation titled "Development of a new compartmental model for plutonium decorporation therapy".

Sara Dumit and her graduate committee: Sayed Daoud, Kathryn E. Meier, Sergei Tolmachev, Jeannie Padowski, Daniel Strom.

Dr. Dumit is the eighth USTUR PhD graduate and the first for the Registries from WSU College of Pharmacy.

On August 20, 2018, Dr. Dumit began working as a postdoctoral research fellow at the Internal Dosimetry Group, Los Alamos National Laboratory (LANL). At LANL, Dr. Dumit continued her research on modeling actinide decorporation therapy.

Internal Dosimetry team (Radiation Protection Division) at Los Alamos National Laboratory.

On December 8, 2018, the USTUR's faculty attended the WSU Commencement and Hooding Ceremony to celebrate Dr. Dumit's graduation.

Dr. Tolmachev places the doctoral hood.

Dr. Dumit with family and USTUR faculty members.

NCRP Scientific Committee 6-12

Sergei Y. Tolmachev, *Associate Research Professor*

In May 2018, Dr. Avtandilashvili and Dr. Tolmachev were appointed to serve on the National Council on Radiation Protection and Measurement's (NCRP) scientific committee (SC 6-12): Development of Models for Brain Dosimetry for Internally Deposited Radionuclides. Letters of appointment are provided as Appendix C. Members of the committee are: Richard W. Leggett (*chairman*, Oak Ridge National Laboratory), Sergei Y. Tolmachev (*vice-chairman*, USTUR), Maia Avtandilashvili (USTUR), Keith F. Eckerman (ORNL, retired), Gayle E. Woloschak (North Western University), Raymond A. Guilmette (s*taff consultant*, Lovelace Respiratory Research Institute, retired).

The detailed description and goals of the committee provided on the NCRP official website are as follows:

Description

SC 6-12 will prepare a commentary that describes new methodological approaches to obtain dose to the brain following intakes of radionuclides. This will help ongoing efforts with regard to the U.S. Department of Energy (DOE) and the National Aeronautics and Space Administration focusing on the effects of high linear-energy transfer (LET) particles in the brain, as well as provide new knowledge on brain dosimetry relevant to protection that has not been available heretofore. Currently, there are no International Commission on Radiological Protection models that provide radiation dose to brain tissue following intakes of radionuclides. However, cohorts of DOE workers (e.g., from Los Alamos National Laboratory, Mallinckrodt Chemical Works, Mound, and Rocketdyne) with intakes of radionuclides that give high-LET dose to brain tissue from alpha-particle emitters amid a low-LET dose from external gamma rays provide a human population receiving radiation somewhat analogous to the exposures received by astronauts in outer space. Of interest is to look at alpha-particle dose to the brain and subsequent risk of dementias, as well as cancer. Radionuclides of interest include polonium, radium, plutonium, americium and uranium, and validation that these cross the blood-brain barrier has come from autopsy material in the U.S. Transuranium and Uranium Registries and Litvinenko. While not equivalent to heavy ion exposures from galactic cosmic rays, using these cohorts has the advantage of providing information after low dose rate (years) for high-LET particles, and measures effect in humans, not mice. In the commentary, the Committee will expand on currently available biokinetic models to include brain dose explicitly.

Goal

To prepare a focused commentary that describes new methodological approaches to obtain dose to the brain following intakes of alpha particle-emitting radionuclides, including modifying currently available biokinetic models to include brain dose explicitly.

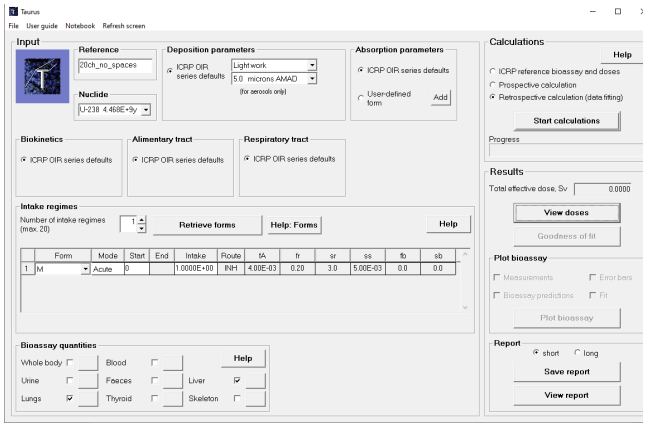
https://ncrponline.org/program-areas/sc-6-12/

Memorandum of Understanding with CRCE

Sergei Y. Tolmachev, *Associate Research Professor*

In February 2019, the Washington State University through the USTUR signed a Memorandum of Understanding (Appendix D) with the Centre for Radiation, Chemical and Environmental Hazards (CRCE), Public Health England. This agreement formalized longstanding collaboration between the two organizations initiated in 1990s by Anthony C. James. This partnership allows PHE to share its newly developed internal dosimetry software, Taurus®, with the USTUR for research purposes at no cost. Initially, the USTUR will test the base model of Taurus®, which is designed for operational dose assessment. However, PHE is also designing an advanced research version, which the USTUR can use for biokinetic modeling and dose assessment of individual registrant cases.

This partnership was facilitated by Sergei Tolmachev and Anthony Riddell (PHE-CRCE Internal Dosimetry Group leader). Mr. Riddell joined the USTUR for its annual Scientific Advisory Committee Meeting in April 2018. He gave a presentation, where he discussed several internal dosimetry software programs, including Integrated Modules for Bioassay Assessment (IMBA®) and PHE's new Taurus®.



Taurus interface screen.

New internal dosimetry software options are important, since further development of IMBA®, which has long been used by the USTUR's researchers, is no longer supported.

National and International Scientist Visits

Stacey L. McComish, *Associate in Research*

Three tours of the USTUR's laboratory facility were given to attendees of the Low Dose Conference in Richland, WA, September 30 – October 3, 2018.

Prior to the meeting, Oleg Belyakov of the International Atomic Energy Agency gave a presentation at the USTUR titled, "Overview of NAHU/ARBR Radiation Biology Coordinated Research Projects". This was followed by a tour of the laboratory facility, which includes an autopsy room, a radiochemistry laboratory, an alpha spectrometry counting room, and a sample storage area.

During the conference, several other individuals expressed interest in a laboratory tour. A tour was given to Michael Bellamy and Sandra Davern of Oak Ridge National Laboratory, and Yuliya Lyamzina of Fukushima Medical University, Japan. The different types of tissue materials that are available at the USTUR, such as frozen organs and paraffin embedded tissue blocks, were discussed. Following the tour, Maia Avtandilashvili demonstrated unique features of the USTUR's academic version of the Integrated Modules for Bioassay Analysis biokinetic modeling software. An additional tour was given to Doug Boreham (Bruce Power, Canada), Stephanie Puukila (Flinders University, Australia and Laurentian University, Canada), Jake Pirkkanen (Laurentian University, Canada), and Christopher Thome (Northern Ontario School of Medicine, Canada).

Oleg Belyakov (in the middle) with USTUR faculty during the laboratory tour.

IRB Changes

Stacey L. McComish, *Associate in Research*

In September 2018, the USTUR submitted a continuing review and a modification to the Central Department of Energy Institutional Review Board (CDOEIRB).

Continuing Review

The continuing review was initially submitted to the CDOEIRB on August 21, 2018. The board required that the USTUR "remove the text at the top of the Personal/Medical History that states the document should be completed by the Registrant or the medical power of attorney." This statement was problematic, because we do not verify medical power of attorney for the person completing the form. The statement was removed, and the continuing review was approved on September 12, 2018 for one year.

The board also recommended that the USTUR re-examine how to address "an aging population and the return of the Personal/Medical History form" due to concerns about the accuracy of information provided. This item was for future consideration, and will be addressed when the project is reviewed in 2019.

Modification

A modification was submitted to increase the number of allowed study participants to 900. The previous cap was 401 participants, based upon the combined number of living and deceased Registrants. However, there were 879 Registrants that had ever been registered to have an autopsy/donate tissues. The new cap allowed for existing living, deceased, and inactive Registrants, as well as up to 21 new Registrants. The modification was submitted on September 27, 2018, and approval was received the same day.

DOE Required Training

CDOEIRB's training requirements differ from those required by WSU's IRB. As such, USTUR staff who interact directly with Registrants and/or work with Registrant data signed DOE's HRP-422 checklist to verify that they had completed the DOE document review and CITI training. These training requirements must be completed every three years.

Registrant Statistics

Stacey L. McComish, *Associate in Research*

As of March 31, 2019, the Registries had 879 Registrants in all categories (Table 1). Of that number, 36 were living and 364 were deceased. The 36 living Registrants included 6 individuals who were registered for eventual whole-body donation, 26 for partial-body donation, and 4 for 'Special Studies,' i.e., a bioassay study with no permission for autopsy. There were also 479 Registrants in an inactive category, which includes those lost to follow-up and those whose voluntary agreements were not renewed.

Table 1. Registrant statistics as of March 31, 2019

Total living and deceased Registrants	400
Living Registrants	36
Potential partial-body donors	26
Potential whole-body donors	6
Special studies	4
Deceased Registrants	364
Partial-body donations	310
Whole-body donations	46
Special studies	8
Total number of Registrants	879

Registrant Renewals

It has been the policy of the USTUR to offer all living Registrants an opportunity to renew their voluntary registrations every five years. Under the 2018 approval from the Central DOE Institutional Review Board, Registrants are no longer required to renew their participation every five years. Instead, they are asked to sign the informed consent and other forms at the point of initial consent, and no additional consent is required. Registrants who have previously signed five-year agreements are sent one-time renewal paperwork shortly before their autopsy authorizations would expire. The forms in this one-time renewal packet will remain valid unless terminated by action of the Registrant or the Registries.

During this fiscal year, 14 Registrants needed to complete a one-time renewal packet. Of these, 12 renewed, one withdrew from the program, and one had not yet completed and returned his renewal paperwork.

Annual Newsletter

The USTUR distributes a newsletter to Registrants and their next-of-kin on a yearly basis (Appendix E). The 2018 letter was mailed in December, and included articles such as "50 years: Learning from Plutonium and Uranium Workers", "Educating the Next Generation", and "Medical Screening".

Registrant Deaths

During this fiscal year, the USTUR received one whole- and one partial-body donation. Both donors worked with plutonium and had estimated systemic burdens in excess of 2 nCi at the end of their employment at a national laboratory. One inhaled about 300 nCi of plutonium, and had a possible ^{244}Cm inhalation. The other had a contaminated wound, and a possible plutonium inhalation.

Registrant Status

The average age of living whole- and partial-body Registrants was 81.9 ± 9.6 years and 83.0 ± 11.8 years, respectively. The average age at death for the

USTUR's 356 deceased whole- and partial-body Registrants was 69.7 ± 13.2 years.

The number of donations by calendar year, as well as the average age of donors by year, is shown in Figure 2.

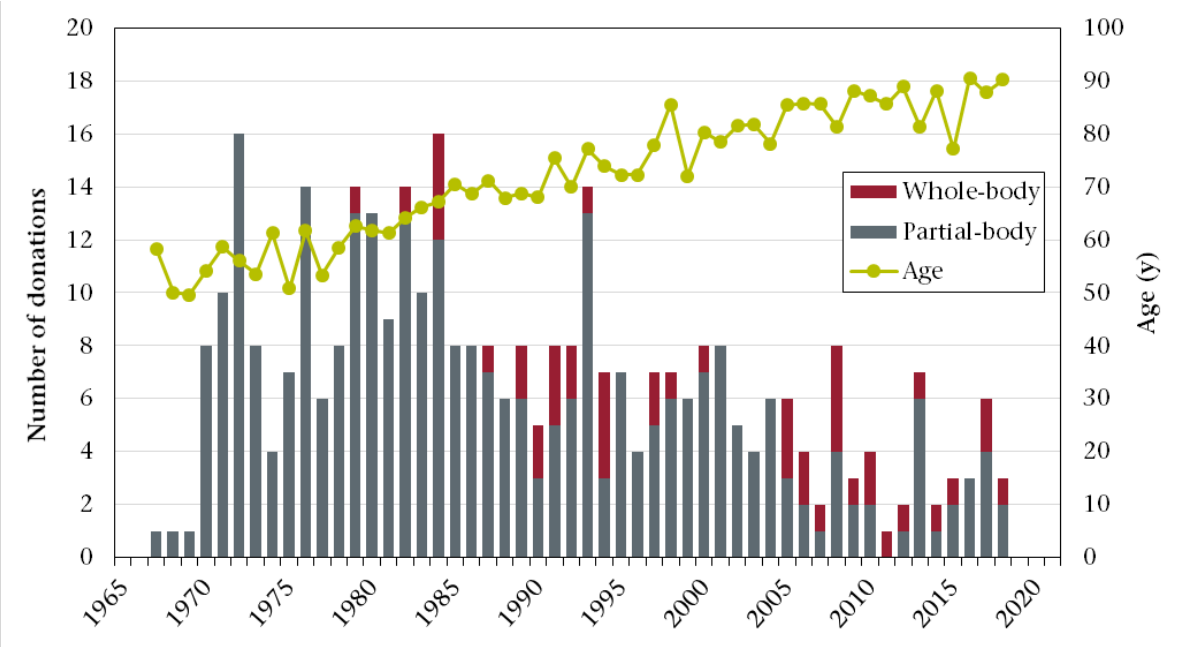


Fig. 2. Number of whole- and partial-body donations by calendar year and average age.

Health Physics Database

Maia Avtandilashvili, *Assistant Research Professor*

The USTUR Internal Health Physics Database is designed to standardize extensive sets of health physics data from USTUR donors and provide access to detailed incident, contamination, *in vitro* and *in vivo* bioassay, air monitoring, work site assessment, external dosimetry, and treatment information for scientists who are interested in studying the distribution and dosimetry of actinides in the human body.

The USTUR currently retains documents containing health physics and bioassay records for 46 whole-body and 310 partial-body tissue donors, as well as 32 living potential donors and 12 special study cases (4 living and 8 deceased).

Since the inception of the health physics database in 2008, the main efforts were focused on standardization of data from deceased Registrants. In 2016, the decision was made to complete population of the health physics database for living Registrants before resuming data entry for remaining donation cases. The availability of standardized exposure information in the database (e.g. route of intake(s), location of contaminated wound(s), material characteristics etc.) for a recently deceased Registrant is essential for determining whether additional samples, such as wound site samples, need to be collected at autopsy.

As of March 31, 2019, standardization of health physics records and bioassay data was completed for 31 living potential donors (six whole-body and 25 partial-body), and 214 deceased donors (46 whole-body and 168 partial-body). In total, 129,874 health physics records from deceased and living Registrants have been entered into the database. In addition, data entry was completed for two special study cases with a total of 504 records. Figure 3 shows FY2019 progress toward population of the database.

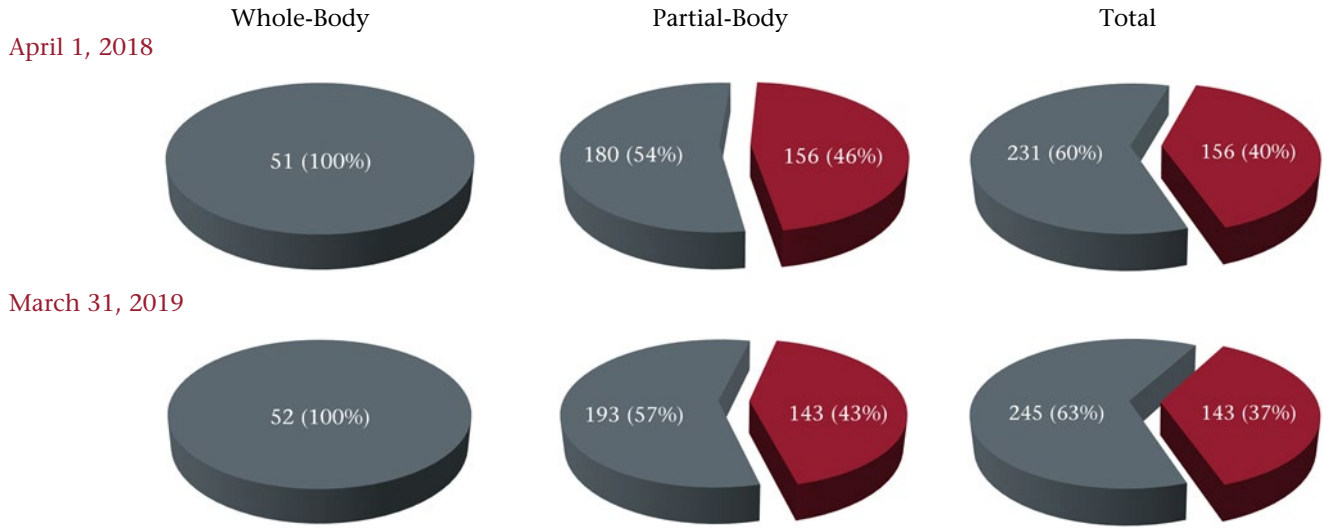


Fig. 3. FY2019 health physics database progress: ■ complete cases; ■ incomplete cases.

Figure 4 shows the FY2008 - FY2019 progress and the overall status of the health physics database as of March 31, 2019.

The summary statistics of all completed cases, categorized based on the type of intake, primary radionuclide of exposure, and material type (solubility class), are presented in Figure 5.

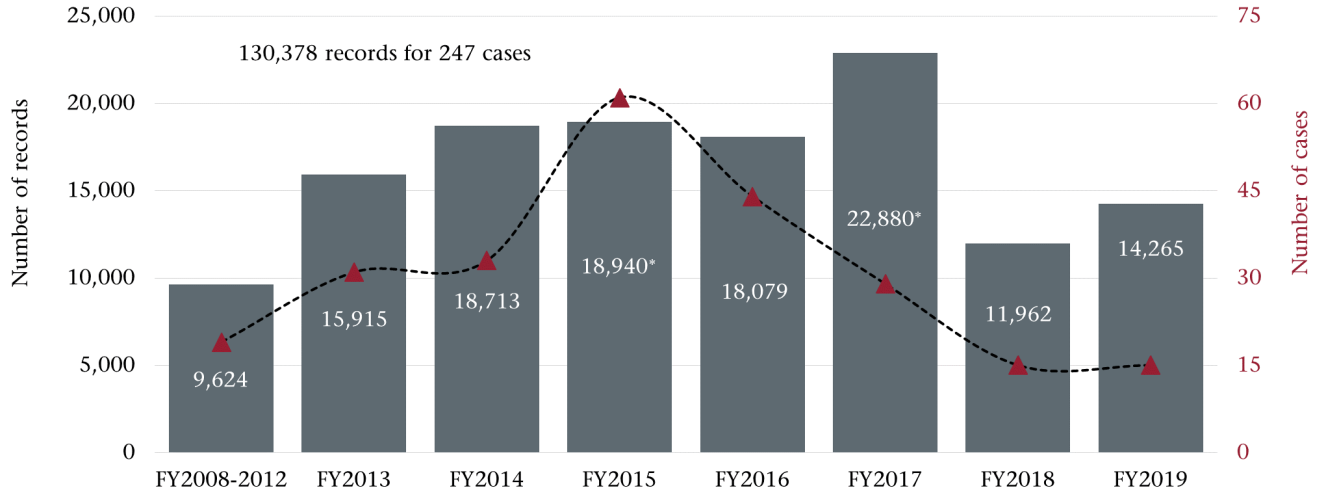


Fig. 4. FY2019 status of the USTUR health physics database. Includes two special study cases completed in FY2015 and FY2017 (*)

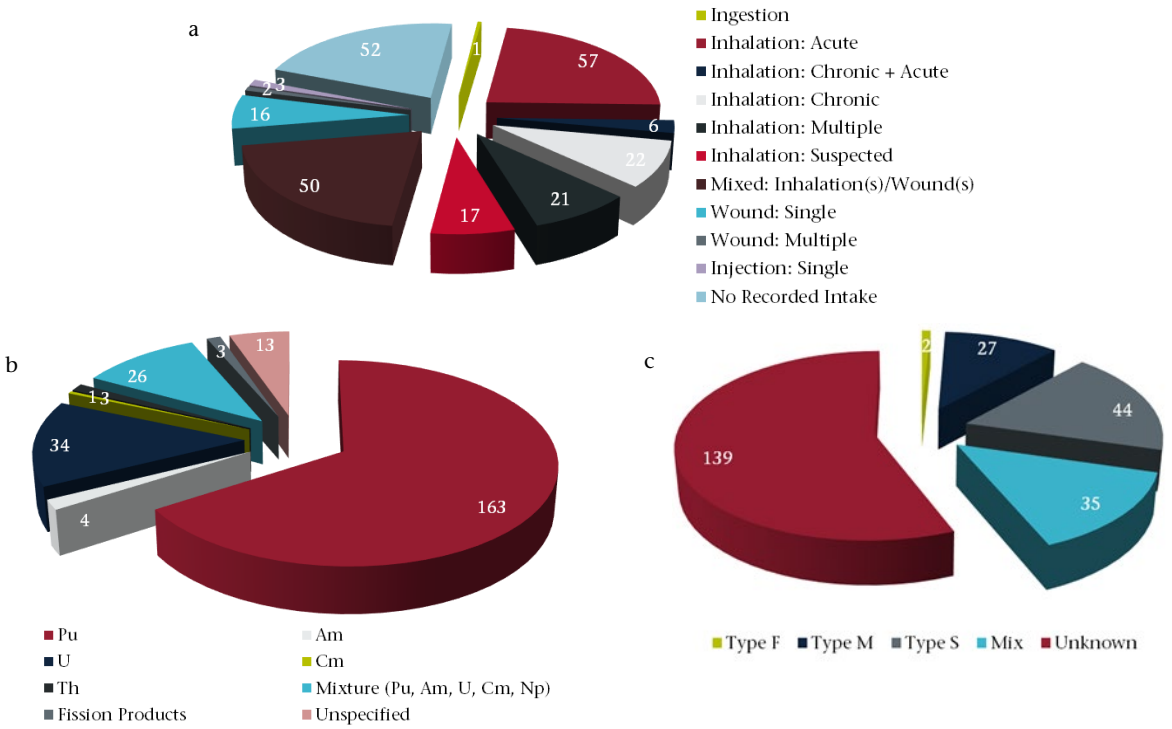


Fig. 5. Summary statistics of the health physics database: completed Registrant cases by intake (a); primary radionuclide (b); material type (c).

National Human Radiobiology Tissue Repository

Stacey L. McComish, *Associate in Research*

The National Human Radiobiology Tissue Repository (NHRTR) houses several collections of tissues and related materials from individuals with intakes of actinide elements and radium. These collections include tissues from USTUR donations, acid dissolved tissues from the Los Alamos Scientific Laboratory's (LASL) population studies, and tissues from the terminated radium worker and plutonium injection studies, which were received from Argonne National Laboratory (ANL).

Three primary activities, related to USTUR tissue donations, were carried out at the NHRTR: autopsies, dissection of donated tissues, and radiochemical analysis of tissues. Each of these activities generated specific samples, which were either stored for future use, or consumed during the radiochemical process. Table 2 summarizes these laboratory activities and the fate of the resulting USTUR samples.

THEMIS Inventory Status

The USTUR uses The Management Inventory System (THEMIS) to electronically inventory NHRTR samples. The USTUR's ultimate aim is to inventory all samples housed at the NHRTR facility. Most samples originating from USTUR tissue donations have already been inventoried. Projects to inventory USTUR tissues, acid solutions, and histology slides were completed during FY2015–FY2016. These projects are in a maintenance phase, where samples are inventoried as they are received and/or generated. Projects to inventory USTUR planchets, LASL acid solutions, and ANL tissues have been initiated; however, due to limited resources, laboratory personnel are focusing their efforts toward completing the LASL acid solution inventory before proceeding with other projects.

Table 2. USTUR samples generated at the NHRTR facility

Laboratory operation	NHRTR samples generated	THEMIS inventory	Storage
Autopsy	Paraffin-embedded tissue blocks	no	yes
	Histopathology slides	yes	yes
Dissection	Frozen and/or formalin-fixed tissues	yes	yes
Radiochemical analysis of tissues			
Drying/Ashing	Ashed tissues	no	no†
Digestion/Dissolution	Acid solutions	yes	yes
Actinide separation	Acid solution aliquots	yes	no†
Alpha spectrometry	α-counting sources (planchets)	yes	yes

† Sample is consumed during radiochemical analysis.

Table 3. Inventory status of NHRTR materials

NHRTR samples	Collection		
	USTUR	ANL	LASL
Frozen and/or formalin-fixed tissues	Maintenance	Deferred	—
Histology slides	Maintenance	Deferred	—
Acid solutions	Maintenance	—	Active
Planchets	Active	—	—

Each inventory project has been assigned a status. "Maintenance" indicates that all historical samples have been inventoried, and new samples will be entered into THEMIS as they are produced or received. "Active" indicates that the inventory of historical samples is ongoing. "Deferred" indicates that laboratory personnel commenced inventorying historical samples, but the project was placed 'on hold' until high-priority projects are completed and/or additional student workers are available. Table 3 summarizes the status of inventory projects.

Tissue Dissection

During FY2019, Florencio Martinez completed the dissection of two whole-body donations and four partial-body donations. Warnick Kernan, Christian Gomez, and Samantha Walter assisted Mr. Martinez and carried out vacuum packaging of tissue samples.

THEMIS Inventory

As of March 31, 2019, 24,262 parent samples and 9,672 subsamples had been inventoried using the THEMIS database (Table 4). Parent samples best represent the number of unique tissues available at the USTUR; therefore, the following discussions about tissues and acid solutions exclude subsamples.

Table 4. Inventoried samples as of March 31, 2019

Tissue type	Samples		
	Parent	Sub-	Total
USTUR donations			
Soft tissue samples	5,085	431	5,516
Bone samples	4,745	76	4,821
Histology slides	1,397	2,096	3,493
Acid solutions	6,454	1,161	7,615
Planchets	0	5,194	5,194
Paraffin blocks	0	39	39
ANL tissues and slides	1,438	436	1,874
LASL solutions	4,447	92	4,539
Blank and QC samples	407	54	461
Miscellaneous	289	93	382
Total	24,262	9,672	33,895

USTUR Tissue Samples

Information on 857 parent samples from recent tissue donations was entered into THEMIS during FY2019. This placed the total number of inventoried USTUR tissues at 9,830 samples from 45 whole-body cases, 113 partial-body cases, and 2 living cases (surgical specimens). The six most common types of USTUR tissues are skeletal, muscle/skin/fat, alimentary, circulatory, respiratory/trachea-bronchial, and nervous. Tissues are typically stored in a frozen state, and skeletal samples are most common due to the large number of bones in the human body, as well as the dissection protocol. On average, whole-body cases had 154 ± 98 tissue

samples per case and partial-body cases had 25 ± 23 tissue samples per case.

Project status – *maintenance*.

USTUR Acid Solutions

In addition to frozen and formalin-fixed tissues, the NHRTR holds thousands of acid-digested tissue samples (acid solutions) that were previously analyzed for actinides. All historical acid samples have been inventoried; however, the number of acid solutions steadily increased, because each time a tissue was dissolved in the radiochemistry lab, the corresponding sample in the THEMIS was changed from a tissue to an acid solution. As of March 31, 2019, the THEMIS inventory contained 6,861 acid solutions.

Project status – *maintenance*.

USTUR Histology Slides

The USTUR holds thousands of microscope slides that were provided by pathologists following USTUR Registrant autopsies. Inventory of new microscope slides is completed as they are received. During FY2019, no new slides were inventoried.

Project status – *maintenance*.

USTUR Planchets

The NHRTR holds several thousand α-spectrometric counting sources (planchets), accumulated by the Registries. A planchet is the final product of an actinide tissue analysis. It is a stainless-steel disk (diameter = 5/8") onto which α-radioactivity was electrodeposited following radiochemical actinide separation. An individual planchet has electroplated activity from one of the following actinide elements: plutonium (Pu), americium (Am), uranium (U), or thorium (Th). Planchets are placed in coin holders for storage. Each coin holder can hold up to eight planchets.

In the past, planchets were inventoried by batch using THEMIS. However, in FY2018, Elizabeth Thomas designed a new in-house planchet database, which works alongside THEMIS to store detailed information about individual planchets.

During FY2019, the old planchet inventory was archived, and a new inventory of individual planchets was commenced. Information on 5,194 planchets was entered into THEMIS, which will be used to track locations, and was linked to the planchets database using each sample's unique barcode.

Project status – *active*.

Los Alamos Scientific Laboratory Acid Solutions

NHRTR staff organized and inventoried acid solutions from population studies carried out by Los Alamos Scientific Laboratory. Bottles were grouped by case number, tested to determine whether they contained nitric (corrosive and oxidizer agent) or hydrochloric (corrosive) acid, paraffin-sealed, and inventoried. During FY2019, 831 LASL acid solutions were inventoried. This brought the total number of inventoried LASL acid solutions to 4,447 from 1,132 autopsies. Commonly inventoried (acid-digested) tissues included liver, lung(s), spleen, kidney(s), bone, thyroid, and lymph nodes.

Project status – *active*.

Argonne National Laboratory Samples

The NHRTR houses an existing collection of tissue materials obtained from the terminated radium worker study at Argonne National Laboratory (ANL) and the historical plutonium injection studies. The

ANL collection consists of frozen and dried tissues, histological slides, and plastic and paraffin-embedded tissues. This collection was acquired by the NHRTR/USTUR in 1992.

No progress has been made toward inventorying the ANL collection due to limited personnel.

Project status – *deferred*.

Inventory Progress

Figure 6 shows the cumulative number of inventoried samples at the end of each calendar year from 2010 to 2019. It can be seen that initial efforts focused on inventorying USTUR tissues and acids. More recently, laboratory personnel focused on LASL and planchets inventories.

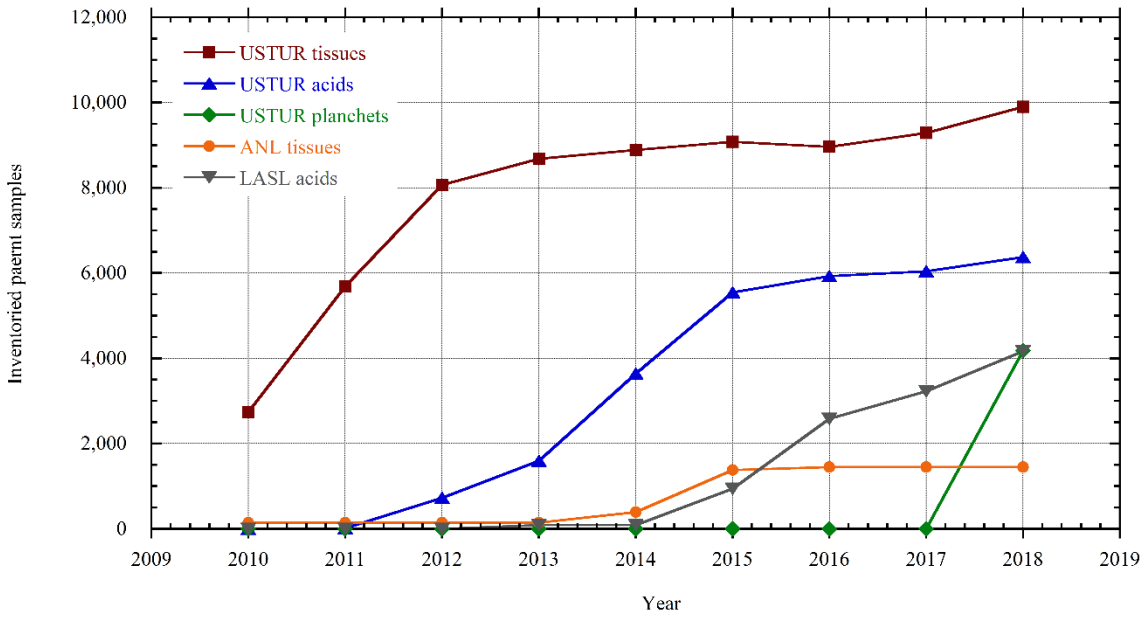


Fig. 6. Cumulative number of inventoried NHRTR samples at the end of each calendar year.

Radiochemistry Operations

George Tabatadze, *Assistant Research Professor*

This section describes specific activities and achievements of the Radiochemistry Group during FY2019.

Personnel

As of April 1, 2019, operation of the radiochemistry laboratory was supervised by Dr. Tolmachev (Principal Radiochemist) with two full-time personnel – Dr. George Tabatadze (Assistant Research Professor) and Ms. Elizabeth Thomas (Laboratory Technician II).

FY2019 Tissue Sample Analysis

Tissue sample analysis is a multi-step process. During the analysis, a tissue undergoes five different analytical steps: (i) drying and ashing, (ii) digestion and dissolution, (iii) radiochemical actinide separation, (iv) preparation of an α-counting source (planchet), and (v) measurement of individual actinides – plutonium (^{238}Pu and $^{239+240}$Pu), americium (^{241}Am), uranium (^{234}U, ^{235}U, and ^{238}U), and/or thorium (^{232}Th).

During FY2019, 342 tissue samples, including 102 bone and 240 soft tissues from 17 donations, were analyzed for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am using α-spectrometry.

Whole-body Donations

In FY2019, analysis of two cerebral lobe samples from two cases, 0635 and 0680, was completed.

Two hundred and twenty-nine tissue samples, including 96 bone and 133 soft tissues from four whole-body donations, cases: 0303 (88 samples), 0471 (37), 0634 (44), and 0674 (60), were submitted for analysis.

Partial-body Donations

In FY2019, analysis of 339 tissue samples from fourteen partial-body donations, received between 1992 and 2017, was completed. Analyzed cases included: 0299 (18), 0315 (24), 0334 (26), 0341 (20), 0371 (17), 0439 (18), 0445 (19), 0446 (24), 0460 (6), 0688 (40), 0695 (50), 0817 (28), 0854 (23), and 0991 (26). A total of 102 bone samples and 237 soft tissues were analyzed for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am. In addition, the mediastinal lymph node from Case 0333 was analyzed.

A total of 135 tissue samples, including 32 bone and 103 soft tissues from three partial-body donations, cases: 0287 (51), 0332 (47), and 0765 (37), were submitted for analysis. In addition, a brain sample from Case 0787 was submitted for analysis.

FY2014 – 2019 Tissue Sample Analysis

Figure 7 shows FY2014 – 2019 tissue analysis progress.

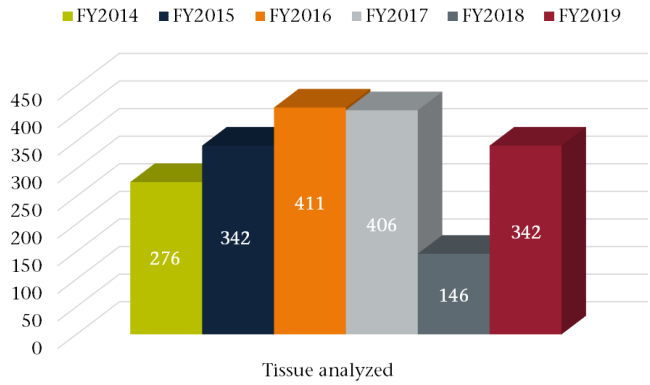


Fig. 7. USTUR tissue analysis progress in FY2014 – 2019.

FY2019 Radiochemistry Case Analysis

As of April 1, 2019, the USTUR had received 46 whole- and 310 partial-body donations, including one whole- and one partial-body donations accepted during FY2019.

In FY2019, tissue samples from two whole-body donors were submitted for survey radiochemical analysis (Table 5).

Table 5. FY2019 whole-body case analysis progress

Case No	Year of donation	Radiochemistry status	
		FY2018	FY2019
0471	2018	Intact	Incomplete
0634	2017	Intact	Incomplete

A new case analysis status - 'Surveyed' was added into radiochemistry database to track case analysis progress. Cases are categorized as 'Intact,' 'Incomplete,' 'Surveyed', or 'Complete'. 'Intact' means that no tissue samples have been analyzed. 'Incomplete' typically denotes that a selected sub-set of tissue analyses is in progress. 'Surveyed' denotes that only analysis of selected tissue samples that provides key scientific information to determine the level of exposure has been completed, and can be used for biokinetic modeling. More tissue samples are available for 'Surveyed' cases. 'Complete' denotes that a full selection of tissue samples was analyzed and results were reported.

Full analyses of 15 partial-body cases were completed, and analyses for three donations are in progress. Table 6 summarizes partial-body case analysis progress. Figure 8 shows FY2014 – 2019 case analysis progress.

Table 6. FY2019 partial-body case analysis progress

Case No	Year of donation	Radiochemistry status	
		FY2018	FY2019
0299	2000	Incomplete	Complete
0315	2004	Incomplete	Complete
0333	1992	Incomplete	Complete
0334	2004	Incomplete	Complete
0341	2004	Incomplete	Complete
0371	1992	Incomplete	Complete
0439	2003	Incomplete	Complete
0445	2003	Incomplete	Complete
0446	1995	Incomplete	Complete
0460	1996	Incomplete	Complete
0688	2017	Incomplete	Complete
0695	2008	Incomplete	Complete
0817	2004	Incomplete	Complete
0854	1995	Incomplete	Complete
0991	2004	Incomplete	Complete
0287	2017	Intact	Incomplete
0332	2017	Intact	Incomplete
0765	2018	Intact	Incomplete

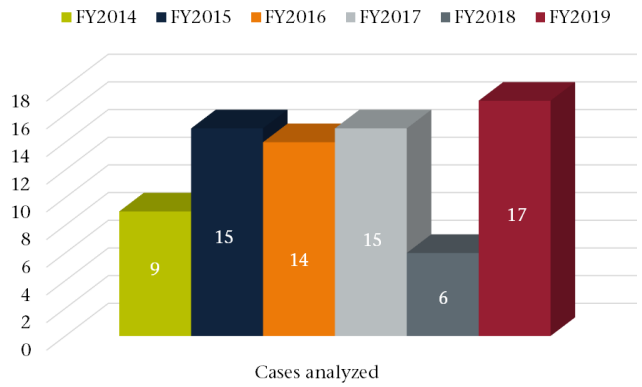


Fig. 8. USTUR case analysis progress in FY2014 – 2019.

The status change of case analyses from FY2018 to FY2019 is shown in Figure 9.

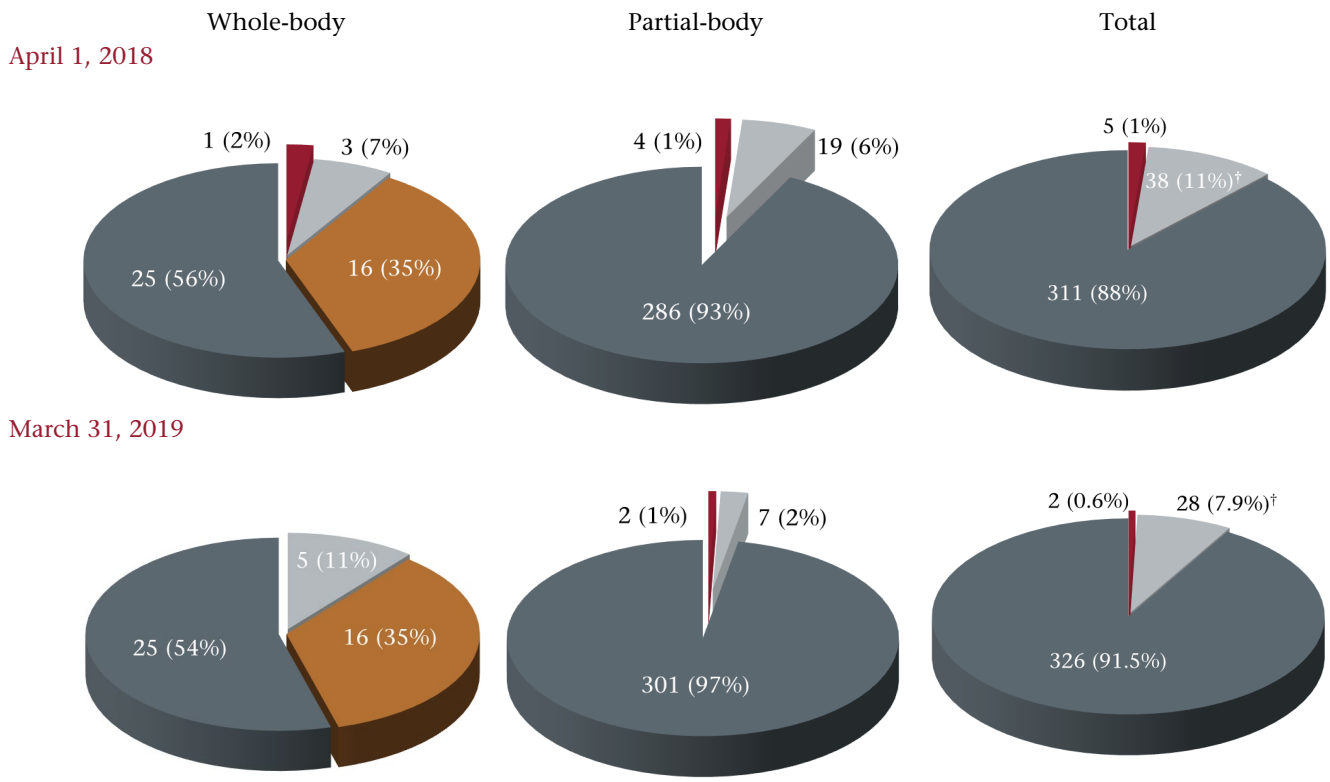


Fig. 9. Radiochemistry case analysis status: ■ Intact; ■ Surveyed; ■ Incomplete; ■ Complete.
† Include 'Surveyed' whole-body cases.

Tissue Sample Backlog

The USTUR/NHRTR retains a tissue backlog of 2,373 samples from 28 whole- and partial-body cases. They remain 'Incomplete' as of April 1, 2019. This includes 1,971 tissue samples from 19 whole-body cases, and 402 tissues from nine partial-body cases. Of 2,373 backlog samples, 2,021 (85%) need to be analyzed for plutonium, 106 (5%) for americium, and 246 (10%) for uranium (Fig. 10).

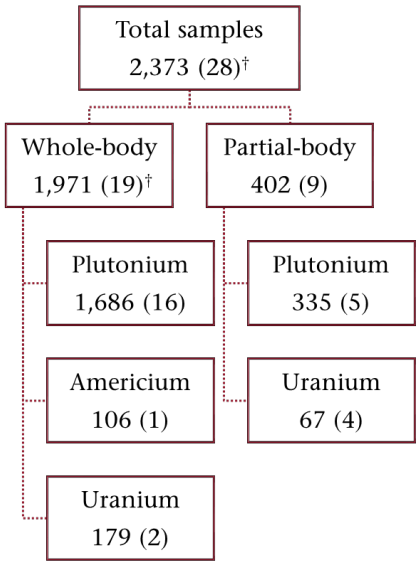


Fig. 10. USTUR tissue sample backlog at the end of FY2019. † Excluding two Thorotrast cases.

Improved Modeling of Pu-DTPA Decorporation

Sara Dumit, *Ph.D. Candidate*

Individuals with significant intakes of plutonium (Pu) are typically treated with chelating agents. The trisodium salt form of calcium diethylene-triaminepentaacetate (Ca-DTPA) is a decorporation drug that forms stable complexes with plutonium in-vivo, enhancing its excretion. Since plutonium's biokinetics is affected by its complexation with this drug, standard biokinetic models cannot be used to estimate plutonium intake. Prior to this work, only ad hoc solutions were available for modeling plutonium biokinetics during and after chelation therapy.

A system of models for plutonium decorporation (SPD) has been developed at the USTUR[1]. The SPD comprises three individual model structures describing, separately, the biokinetic behaviors of systemic plutonium, the intravenously injected chelating agent, and the in vivo-formed chelate (actinide-drug, Fig.11).

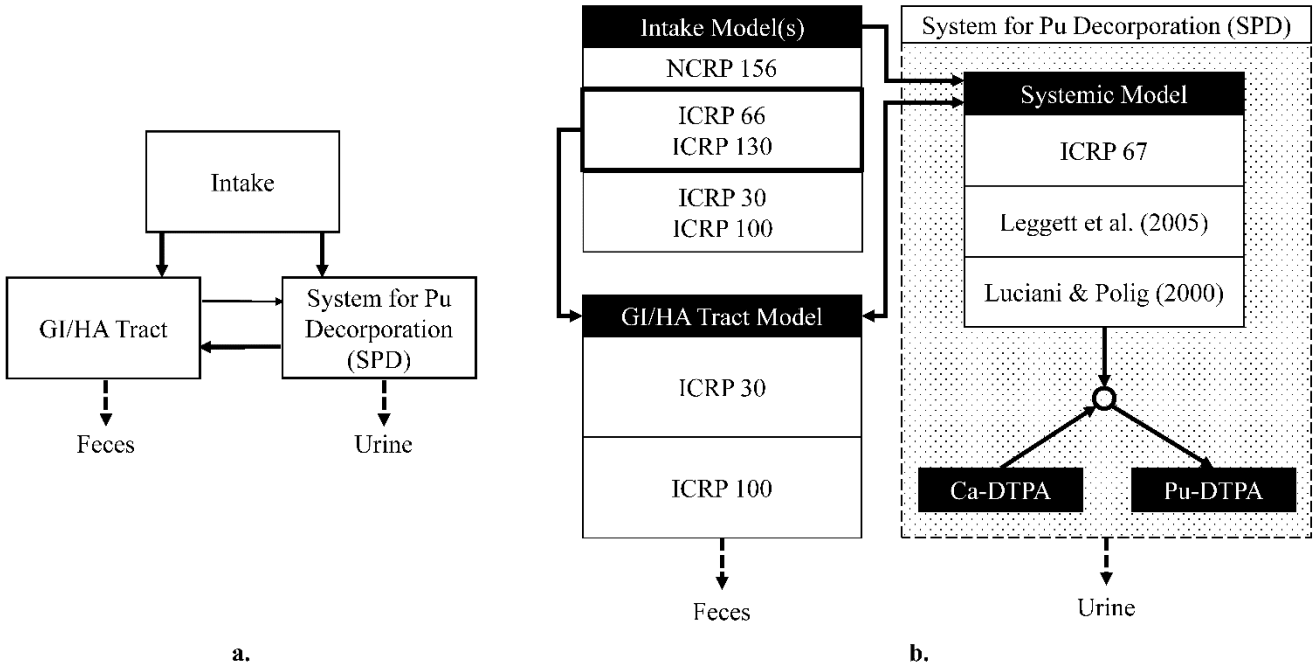


Fig. 11. Combined system of biokinetic models: simplified (a) and comprehensive (b) view[2].

The Coordinated Network for Radiation Dosimetry (CONRAD) approach to decorporation modeling is applied by using a chelation constant to describe the second-order kinetics of the in vivo chelation reaction[3]. In the proposed SPD, chelation occurs in the blood, soft tissues, skeleton, and liver.

The SPD was developed using data from USTUR whole-body donor (Case 0212), an individual exposed to plutonium via wound[1,4]. Urine

measurements and post-mortem plutonium activities in the liver and the skeleton from Case 0212 were used for model development and initial validation, respectively. The model was implemented in SAAM II® software with the Leggett et al. plutonium systemic model[5], the International Commission on Radiological Protection (ICRP) Publication 100 human alimentary tract model[6], and the National Council on Radiation Protection and Measurements' Report 156 wound model[7].

To validate the SPD, data from a whole-body donor exposed via inhalation were used. USTUR Case 0269 inhaled moderately soluble plutonium and was treated extensively with chelation agents. Chelation treatment data, urine measurements, and post-mortem plutonium activities in USTUR Case 0269's skeleton and liver were used in this study. The SPD was linked to the ICRP Publication 130 Human Respiratory Tract Model[8] and the ICRP Publication 100 Human Alimentary Tract Model[6] to evaluate the goodness-of-fit to the urinary excretion data and the predictions of post-mortem plutonium retention in the skeleton and the liver.

The model developed in this work simultaneously fits the chelation-affected and non-affected urinary excretion data, and predicts autopsy data in major deposition sites.

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Brain Dosimetry for Internal Emitters

Sergei Y. Tolmachev, *Associate Research Professor*

Element-specific biokinetic models are used to reconstruct doses to systemic tissues from internal emitters. These models typically explicitly depict only those tissues that tend to dominate the systemic behavior of the element over time. The remaining tissues are aggregated into a pool called *Other tissue*, in which activity is assumed to be uniformly distributed. Explicitly identified tissues usually consist of some subset of liver, kidneys, bone, bone marrow, gonads, thyroid, spleen, and skin tissues.

The brain is explicitly included in systemic biokinetic models for a few elements, but typically is addressed as an implicit mass fraction of *Other tissue*. There is an increasing interest in the potential adverse effects of internal emitters, particularly alpha emitters, on the brain as limited analogues for galactic cosmic ray (GCR) exposures during space travel and for possible radiogenic effects on the brain in nuclear medicine patients and radiation workers. For National Aeronautics and Space Administration, the need is to provide protection against in-flight behavioral and cognitive impairments from GCRs on the central nervous system, as well as against long-term dementia and motor neuron diseases[1,2]. The Million Person Study (MPS) is estimating brain doses from exposure to radionuclides and evaluating dementia, Alzheimer's disease, Parkinson's disease, and motor neuron disease as possible adverse outcomes of combined high- and low-LET exposures of brain tissue[2,3].

In this study, potential improvements in brain dosimetry from alternate (explicit) modelling of brain kinetics, instead of treating the brain as an implicit mass fraction of *Other tissue*, were evaluated. Comparisons were made of dose coefficients for selected radionuclides, based on alternate versions of the systemic biokinetic model for each radionuclide, differing only in the handling of brain tissue.

As an illustration, the systemic model for plutonium used in the MPS[4] includes the brain implicitly in *Other* tissue (Fig. 12a). The most relevant brain-specific data available for modelling brain kinetics of plutonium appears to be autopsy data from nuclear workers. The activity of ^{239}Pu in the brain was measured post mortem in several USTUR Registrants. As a central estimate (either mean or median) for these individuals, the brain contains ~0.2% as much ^{239}Pu as the liver and skeleton combined. Based on USTUR data, a single compartment representing the brain was added to the plutonium model (Fig. 12b), and parameter values for the brain were set to yield a long-term total activity ratio *brain-to-(liver + skeleton)* of 0.002.

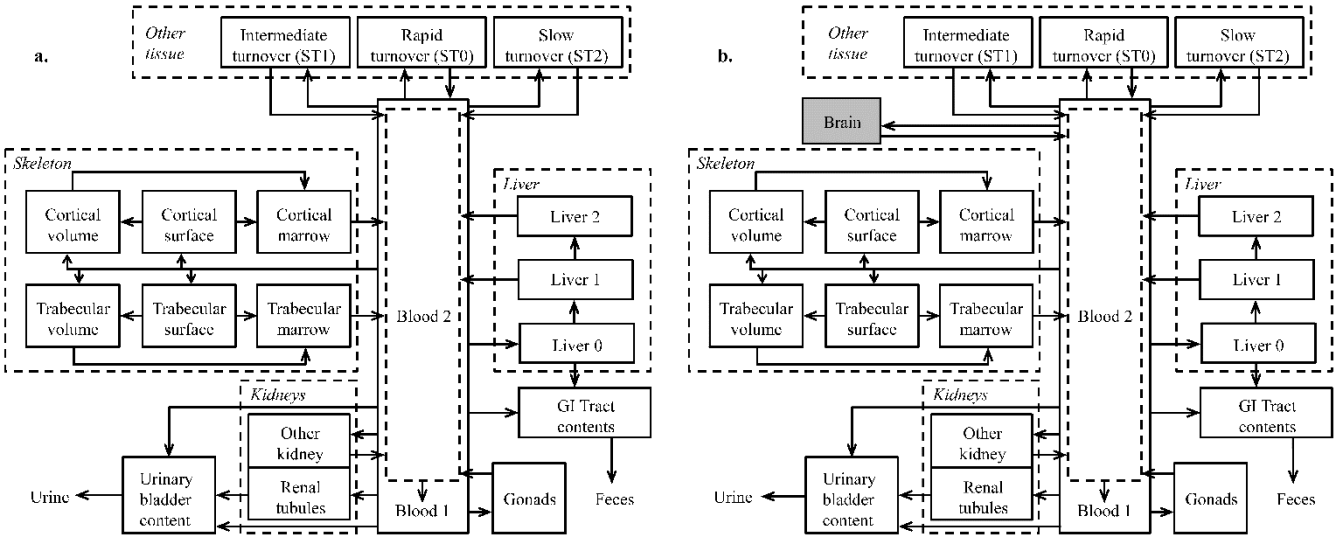

Fig 12. Systemic model for plutonium: current version with brain included in *Other tissue* (a); alternate version with explicit brain (b).

Table 7 compares dose coefficients for the brain for ^{239}Pu and other radionuclides, based on alternate versions of the systemic biokinetic model for each radionuclide: Version A, which includes the brain implicitly in *Other tissue,* and Version B, which explicitly depicts a brain pool with kinetics based on brain-specific radiobiological data. An acute input of the radionuclide into the blood is assumed.

As illustrated in Table 7, results of the study to this point suggest that explicit biokinetic modelling of a brain pool for elements of interest is likely to result in a moderate increase in estimated dose to the brain from most internal emitters.

Table 7. Comparison of dose coefficients (Sv Bq^{-1}) for brain for acute input to blood, based on biokinetic model with brain included in *Other tissue* and modified version with an explicit brain pool

Nuclide	Version of biokinetic model		Ratio B:A
	(A) *Implicit* brain	(B) *Explicit* brain	
^{134}Cs	5.9×10^{-9}	7.6×10^{-9}	1.5
^{54}Mn	1.4×10^{-9}	2.4×10^{-9}	1.7
^{203}Hg vapour	6.4×10^{-10}	9.0×10^{-10}	1.4
^{210}Po	3.1×10^{-7}	5.4×10^{-7}	1.7
^{239}Pu	2.2×10^{-5}	2.6×10^{-5}	0.96

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Biokinetics of Soluble Plutonium after Wound Injury Treated with Ca-DTPA

Maia Avtandilashvili, *Assistant Research Professor*

The USTUR holds records on exposure history and bioassay measurements, as well as post-mortem tissue radiochemical analysis results for 19 individuals who had documented intakes of ^{239}Pu due to contaminated wounds. For 8 individuals, internal deposition resulted from a single wound injury, and three of them were treated with decorporation therapy. In this study, USTUR Case 0303 was used to study biokinetics of soluble plutonium after wound intake.

The USTUR whole-body donor (Case 0303) was employed at a nuclear defense facility for 30 years. While working in a glove-box, he accidentally punctured his finger on a sharp object contaminated with plutonium nitrate. The contaminated tissue was surgically excised and found to contain approximately 2.33 kBq of ^{239}Pu with 0.78 kBq still remained in the finger. Worksite personnel estimated systemic deposition of ^{239}Pu due to this accident as 85 Bq. This individual was medically treated with intravenous injections of Ca-DTPA. A total of 16 g Ca-DTPA was administered in 18 treatments during two months following the accident. Eighty-seven urine samples were collected and analyzed over 14 years following the accident. This individual died 40 years post-intake at age 87.

Thirty-two soft tissue and 8 bone samples collected at autopsy were radiochemically analyzed for ^{238}Pu, ^{239}Pu, and ^{241}Am. A complete description of the radiochemical analysis protocol has been described elsewhere[1]. To estimate the plutonium intake, late urine measurements (past 100 days after the last Ca-DTPA injection), which were unaffected by chelation, and post-mortem radiochemical analysis results were evaluated using the IMBA Professional Plus® software[2].

Post-mortem radiochemical analysis of autopsy tissues indicated that 40 years post-accident, 12.2 ± 0.3 Bq of ^{239}Pu was retained in the liver, and 17.5 ± 0.7 Bq in the skeleton. Activity measured in the skin and muscle tissue sample from the wound site was 0.26 ± 0.01 Bq, while activity in the finger bone adjacent to the wound was measured as 1.09 ± 0.03 Bq. Thus, a total of 1.35 Bq of ^{239}Pu was retained in the wound.

Activity in the lungs, including thoracic lymph nodes, was estimated to be 0.14 ± 0.01 Bq, two orders of magnitude lower than the activity in the liver. This observation confirmed the assumption of the soluble plutonium intake via wound injury to be the major source of internal contamination for this individual.

Application of the NCRP 156 wound model[3] with default parameters for soluble strong material resulted in a credible fit to the data ($p > 0.05$) (Fig. 13). The residual intake was estimated to be 47.6 Bq and estimated committed effective dose was 24.1 mSv. By accounting for ~70.5 Bq of ^{239}Pu excreted during Ca-DTPA treatment, the total intake was estimated to be 118 Bq. Without Ca-DTPA treatment,

this individual would have received committed effective dose of 59.8 mSv. Chelation therapy reduced radiation dose by a factor of 2.5.

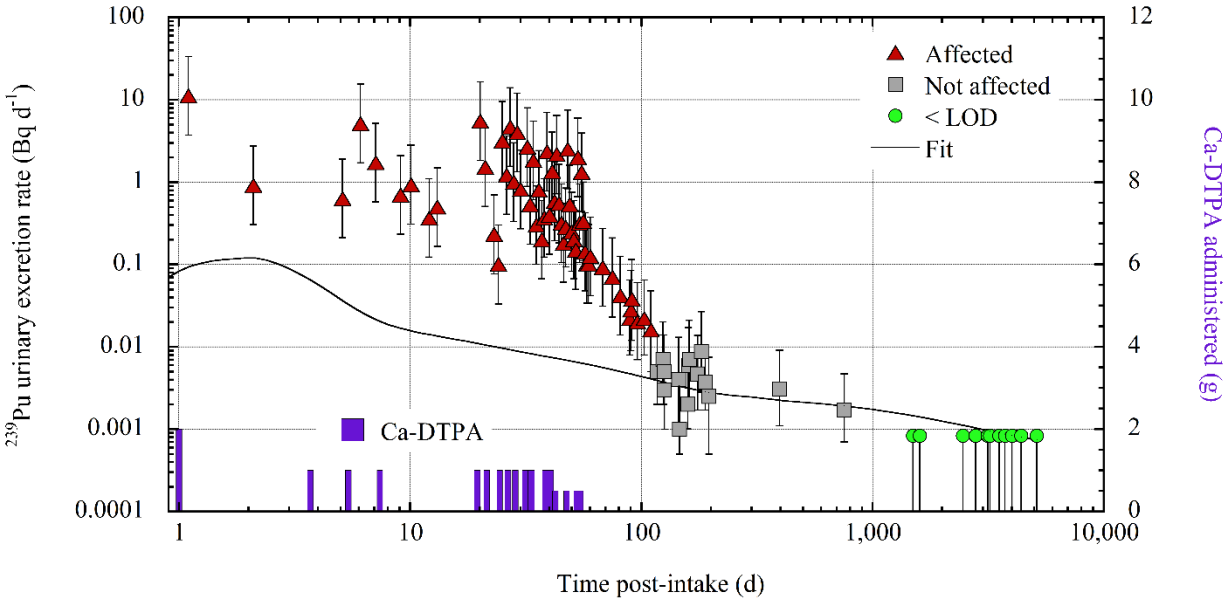

Fig. 13. ^{239}Pu daily urinary excretion and Ca-DTPA treatment data.

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2018 Advisory Committee Meeting Summary

Roger O. McClellan, *Chair*

The annual meeting of the USTUR's Scientific Advisory Committee (SAC) was moved from fall to spring to better align with the USTUR's fiscal year. Thus, the 2018 SAC meeting was held April 26-27 at the Hampton Inn, Richland, WA. The meeting agenda is attached as Appendix F.

2018 Meeting Attendees

The Scientific Advisory Committee, USTUR faculty/staff, colleagues from WSU College of Pharmacy, and several invited guests attended the 2018 meeting. All participants were invited to attend Thursday's presentations, and the Friday morning session; however, the Friday afternoon session was executive in nature, and attended only by SAC members, USTUR staff, and the DOE program manager.

Advisory Committee

- Luiz Bertelli, *Health Physics*
- Timothy Ledbetter, *Ethics*
- Roger McClellan, *Toxicology (Chair)*
- Thomas Rucker, *Radiochemistry*
- Arthur "Bill" Stange, *Occupational Health*
- Unable to attend: Heather Hoffman, *Epidemiology*

Department of Energy

- Joey Zhou, *Program Manager*

U.S. Transuranium and Uranium Registries

- Sergei Tolmachev, *Director*
- Stacey McComish, *Associate in Research*
- Maia Avtandilashvili, Assistant *Research Professor*
- George Tabatadze, Assistant *Research Professor*
- Elizabeth Thomas, *Laboratory Technician II*
- Margo Bedell, *Fiscal Specialist I*
- Sara Dumit, *Ph.D. Candidate, College of Pharmacy*
- Florencio Martinez, *Medical Technologist*
- Daniel Strom, *Adjunct Faculty*

Washington State University

- Ronald Kathren – *Professor Emeritus*
- Kathryn Meier – *Associate Dean for Faculty and Student Development, College of Pharmacy*
- Donald Wall, *Nuclear Science Center, Director*

Invited Guests

- Cheryl Antonio, *NV5*
- John Brockman, *University of Missouri* Research Reactor
- Darrell Fisher, *Versant Medical Physics and Radiation Safety*
- Bruce Napier, *PNNL*
- Anthony Riddell, *Public Health England*
- Christopher Roice, *Framatome*
- Michael Simmons, *CCG.*

Presentations

WSU/College of Pharmacy News – Meier, K.

Dr. Meier summarized news from WSU Spokane's campus and the College of Pharmacy and Pharmaceutical Sciences. Topics included WSU Spokane's new chancellor and the College of Pharmacy's recent name change.

Introducing a new SAC member – Bertelli, L.

Dr. Bertelli introduced himself with a brief summary of the work carried out by Los Alamos National Laboratory's Internal Dosimetry Group. He discussed operational activities, such as routine monitoring of workers, as well as participation on committees and planned research topics for collaboration with the USTUR.

2018 Financial & Administrative Development – Bedell, M.

Ms. Bedell summarized administrative and financial information including: personnel support, the FY2018 budget vs. spending, the FY2019 budget, and salary increases. Additionally, the Anthony C. James scholarship fund reached its goal of $25,000, and is now an endowed scholarship.

2017 SAC Recommendations & 2018 Overview – Tolmachev, S.

Dr. Tolmachev described the USTUR's response to each of the SAC's recommendations from last August's meeting. This was followed by an overview of FY2018 activities, which included: conference presentations, lectures, and seminars; professional services; accepting donations; health physics, NHRTR, and radiochemistry databases; radiochemical analyses; and the upcoming special issue of Health Physics.

Registrant Statistics and IRB Changes – McComish, S.

Ms. McComish briefly summarized Registrant statistics, and explained changes associated with the USTUR's new IRB of record, the Central DOE IRB. Specifically, Registrants are no longer required to sign renewal paperwork every 5 years, and the USTUR will no longer enroll new Registrants postmortem.

USTUR Health Physics Database – Avtandilashvili, M.

Dr. Avtandilashvili discussed the structure and scope of the USTUR's in-house health physics database. Information about completed cases, such as route of intake and worksite, was provided. A progress report indicated that 116,380 records from 233 cases had been entered into the database.

National Human Radiobiological Tissue Repository – McComish, S.

Ms. McComish provided the status (maintenance, active, or future) of inventory projects at the NHRTR. Data trends for the number of inventoried samples indicated that laboratory personnel first focused in inventorying USTUR tissues, followed by USTUR acid solutions, acid solutions from Los Alamos Scientific Laboratory population studies, and historical Argonne National Laboratory samples.

2018 Radiochemistry Progress Report – Tabatadze, G.

Dr. Tabatadze described operation of the radiochemistry laboratory. Topics included tissue analyses, evaluation of analytical methods, equipment upgrades, facility maintenance, equipment repair, and the design of the USTUR's in-house radiochemistry database.

Development of New Compartmental Model for Plutonium Decorporation – Dumit, S.

Ms. Dumit described a new compartmental model for plutonium decorporation, which she developed using USTUR data. The new model was validated using autopsy data and an additional USTUR case, and its ability to fit urinary excretion data was compared to fits produced by the previously published CONRAD model.

Internal Dosimetry Software Development (from Pluto to Taurus) – Riddell, A.

Mr. Riddell discussed internal dosimetry software including Pluto, Massass, IMBA, and Public Health England's new software, Taurus. The base version of Taurus, which implements ICRP's Occupational Intakes of Radionuclides (OIR) methodology for operational dose assessment purposes, was demonstrated. In the future, an advanced version of Taurus will be developed for use in research.

Research at University of Missouri Research Reactor Center – Brockman, J.

Dr. Brockman discussed several studies that used the results of trace element analyses to conduct epidemiological research. Additionally, his research team has investigated the relationship between the isotopic ratios of uranium and plutonium and self-reported exposures to these elements.

Operation & Research at WSU Nuclear Science Center – Wall, D.

Dr. Wall provided an overview of the broad range of research and operations carried out at WSU's Nuclear Science Center. Topics included container fabrication and shipping, safety analyses, target production, single crystal x-ray diffraction, the epithermal neutron beam, and the cobalt-60 irradiator.

Research Plan and Operation in FY2019 – Tolmachev, S.

The USTUR's research and operational goals for the next year were summarized. Topics included: management and operation of the Registries, conducting scientific research, and demonstrating/promoting the broader use of USTUR research, data, and materials.

Comments

Specific comments included:

1. The proposed mission statement is improved in pointing toward using the data for biokinetic/dosimetric models.
2. We are pleased with progress in demonstrating value to DOE officials. Continued progress and expansion are encouraged (see recommendations).
3. The USTUR productivity in publications this year is to be commended.
4. The USTUR has shown significant effort toward identifying collaboration opportunities with outsiders this year.
5. We are disappointed with the limited progress on development of DQO/MQOs.

Recommendations

1. To assure the confidentiality of individuals' information, add to the mission statement that all research and collaborative efforts will be in keeping with the Privacy Act requirements and IRB approval.
2. Continue and enhance publication of papers and presentations with broadened scope and audience (external and internal).
3. Produce a list of identified potential collaborators.
4. Create a Quality Assurance Plan that includes 1) the Mission Statement, 2) the data required to meet the Mission Statement Objectives, 3) the Measurement Quality Objectives (accuracy, precision, sensitivity, selectivity, completeness, etc.), and 4) the quality control limits for the different measurement parameters that monitor and control the MQOs. Quality Assurance Project

Plans may also be developed for specific collaboration needs.

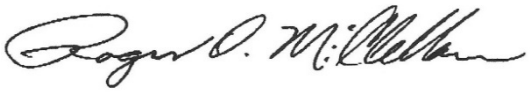
5. Complete implementation of the initiative for collecting bioassay monitoring data from living Registrants.
6. Need to complete 5-year, and 10-year plans by establishing benchmark completion dates for stated goals.
7. Enhance relationship with WSU Tri-Cities and Pullman campuses in collaborative development of research projects and student involvement through interface at all levels of the organizations. Take advantage of doors that have been opened at the Nuclear Science Center.
8. Develop a written operating procedure for control, release, and potential return of data and tissues that lists responsibilities and authorizing individuals.

SAC Membership

Luiz Bertelli joined the SAC as a health physics representative. He filled a vacancy left by Richard Toohey last September.

Note of Appreciation

The assistance of Stacey McComish in preparing the meeting summary is gratefully appreciated.



Roger O. McClellan

SAC Chair

Professional Activities and Services

During FY2019, the USTUR staff was actively involved in professional and academic activities nationally and internationally.

Academic Services

WSU Graduate Committee

Dr. Tolmachev (chair) and Dr. Strom (member) completed their service on WSU Graduate Committee for College of Pharmacy and Pharmaceutical Sciences PhD candidate Sara Dumit.

Professional Services

NCRP Council Committee 2

Dr. Tolmachev continued to chair the Radio- and Nuclear Chemistry Sub-committee of the National Council on Radiation Protection and Measurement (NCRP) Council Committee 2.

https://ncrponline.org/program-areas/cc-2/

NCRP Scientific Committee 6-12

Dr. Tolmachev and Dr. Avtandilashvili were appointed to serve on the NCRP scientific committee (SC 6-12) on the development of models for brain dosimetry for internally deposited radionuclides. Dr. Tolmachev is a vice-chairman of the committee.

https://ncrponline.org/program-areas/sc-6-12/

Herbert M. Parker Foundation

Dr. Tolmachev continued to serve as a member of the Board of Trustees for the Herbert M. Parker Foundation.

https://tricities.wsu.edu/parkerfoundation/

Health Physics Society International Collaboration Committee

Dr. George Tabatadze continued to serve as a member of, the International Collaboration Committee (ICC) of the Health Physics Society (HPS). Appointment: 2016–2019.

https://hps.org/aboutthesociety/organization/committees/committee9.html

Columbia Chapter of Health Physics Society

Dr. Tabatadze has become the president of the Columbia Chapter of the Health Physics Society (CCHPS). He began his three-year term in July 2017 to serve one-year terms as the president-elect, president, and past president between 2017 – 2019, respectively.

https://www.cchps.org/executive-council

Kyushu Environmental Evaluation Association

Dr. Tolmachev continued to serve as a Technical Advisor at the Kyushu Environmental Evaluation Association (Fukuoka, Japan).

http://www.keea.or.jp/

Scientific Meetings

USTUR faculty and Ms. Dumit, PhD candidate, attended and participated in the following scientific meetings:

- 3rd Workshop of the Million Person Study, Oak Ridge Associated Universities (ORAU), Oak Ridge, TN, May 2 – 5, 2018
- Brazilian Graduate Student Conference (BRASCON), Columbus, OH, June 23-24, 2018
- 63rd Annual Health Physics Society Meeting in Cleveland, OH, July 15 – 19, 2018
- Conference on Radiation & Health, Chicago, IL, September 23 – 25, 2018
- 64th Annual Meeting of Radiation Research Society, Chicago, IL, September 23 – 26, 2018

- American Nuclear Society & Health Physics Society's Joint Topical Conference on Applicability of Radiation-response Models to Low Dose Protection Standards, Tri-Cities, WA, September 30 – October 3, 2018
- 12th International Conference on Health Effects of Incorporated Radionuclides, Fontenay-aux-Roses, France, October 8 – 11, 2018
- WSU Department of Chemistry Research Seminar, Pullman, WA, October 26, 2018
- 4th Workshop of the Million Person Study, Oak Ridge Associated Universities (ORAU), Oak Ridge, TN, October 31 – November 2, 2018
- Centre for Environmental Radioactivity Workshop on Health Effects Following Severe Nuclear Events, Oslo, Norway, February 3, 2019
- Centre for Environmental Radioactivity Workshop on Particle Characteristics and Nuclear Forensics, Oslo, Norway, February 5, 2019
- 5th Workshop of the Million Person Study, Oak Ridge Associated Universities (ORAU), Oak Ridge, TN, February 27 – March 1, 2019.

Editorial Services

Japanese Journal of Health Physics

Dr. Sergei Tolmachev continued to serve as a member of the Editorial Board for the *Japanese Journal of Health Physics* (JJHP) for his 3rd term from August 2017 to July 2019.

Austin Biometrics and Biostatistics

Dr. Maia Avtandilashvili continued to serve as a member of the Editorial Board for the journal of *Austin Biometrics and Biostatistics*:

http://austinpublishinggroup.com/biometrics/editorialBoard.php

Professional Affiliations

The USTUR personnel are active members of numerous national and international professional organizations:

- Radiation Research Society (USA)
- Health Physics Society (USA)
- Japan Health Physics Society (Japan)
- European Radiation Dosimetry Group (EURADOS), Working Group 7 (WG7) on Internal Dosimetry (EU).

Publications and Presentations

The following manuscripts and presentations were published or presented during the period of April 2018 to March 2019. Previous manuscripts and abstracts are available on the USTUR website at: ustur.wsu.edu/Publications/index.html

Abstracts of published peer-reviewed manuscripts and scientific presentations are included in Appendix G of this report.

Published

USTUR-0472-17

Dumit S, Avtandilashvili M, Strom DJ, McComish SL, Tabatadze G, Tolmachev SY. Improved modeling of plutonium-DTPA decorporation. *Radiation Research* 191: 201-210; 2019.

USTUR-0495-18

Schneider NR, Xie T, Glover SE, Tolmachev SY, Dong Z, Spitz HB. Determination of 232Th and progeny in human reticuloendothelial tissues using alpha particle track autoradiographic microdosimetry from Thorotrast. *Journal of Radioanalytical and Nuclear Chemistry* 318(1): 235-239; 2018.

USTUR-0496-18

Boice JD, Leggett RW, Eckerman KF, Tolmachev SY, Woloschak GE, Golden AP, Ellis ED. Response to Mortazavi et al. on Detecting bone-seeking radionuclides in brain tissue. *Health Physics* 115(3): 389-390; 2018.

USTUR-0500-18

Dumit S, Avtandilashvili M, McComish SL, Strom DJ, Tabatadze G, Tolmachev SY. Validation of a system of models for plutonium decorporation therapy. *Radiation and Environmental Biophysics*; Epub ahead of print; 2019. doi: 10.1007/s00411-018-00773-y

USTUR-0502-18

Leggett RW, Tolmachev SY, Boice JD. Potential improvements in brain dose estimates for internal emitters. *International Journal of Radiation biology*; Epub ahead of print; 2018. doi: 10.1080/09553002.2018.1554923

USTUR-0435-16

Breustedt B, Avtandilashvili M, McComish SL, Tolmachev SY. USTUR Case 0846: Modeling americium biokinetics after intensive decorporation therapy. Epub ahead of print; 2018. doi: 10.1097/HP.0000000000000931

USTUR-0432-16

Tabatadze G, Miller BW, Tolmachev SY. Digital autoradiography of ^{241}Am spatial distribution within trabecular bone regions. *Health Physics*: Epub ahead of print; 2018. doi: 10.1097/HP.0000000000000947

USTUR-0427-16

Kathren RL, Tolmachev SY. The United States Transuranium and Uranium Registries (USTUR): A five decade follow-up of plutonium and uranium workers. *Health Physics*: Epub ahead of print; 2018. doi: 10.1097/HP.0000000000000963

USTUR-0430-16

Avtandilashvili M, Tolmachev SY. Modeling skeleton weight of an adult Caucasian man. *Health Physics*: Epub ahead of print; 2018. doi: 10.1097/HP.0000000000000881

USTUR-0431-16

Dumit S, Avtandilashvili M, Tolmachev SY. Evaluating plutonium intake and radiation dose following extensive chelation treatment. *Health Physics*: Epub ahead of print; 2018.
doi: 10.1097/HP.0000000000000882

USTUR-0497-18A

Dumit S, Strom D, McComish SL, Avtandilashvili M, Tabatadze G, Tolmachev SY. New biokinetic model simultaneously fits Ca-DTPA affected and non-affected urine bioassay data after plutonium contamination. *Health Physics* 115 (1 Suppl): S83; 2018.

USTUR-0498-18A

Strom DJ. A simple visualization of the LEKSKaM 2005 model of systemic plutonium biokinetics. *Health Physics* 115 (1 Suppl): S82-S83; 2018.

USTUR- 0501-18

McComish SL, Tolmachev SY. United States Transuranium and Uranium Registries Annual Report: April 1, 2017 – March 31, 2018. United States Transuranium and Uranium Registries; USTUR-0501-18, Richland, WA, 2018.

Presented

Invited

USTUR-0505-18A

Tolmachev SY. The US Transuranium and Uranium Registries: 50 years of contributions to plutonium in humans. Podium presentation at the Conference on Radiation and Health, Chicago, IL, September 23 – 25, 2018.

USTUR-0506-18A

Avtandilashvili M, McComish SL, Tolmachev SY. The United States Transuranium and Uranium Registries: Fifty-year history of actinide biokinetic research. Podium presentation at the 12th International Conference on Health Effects of Incorporated Radionuclides, Fontenay-aux-Roses, France, October 8 – 11, 2018.

USTUR-0514-18P

Tolmachev SY. The United States Transuranium and Uranium Registries: Fifty-year history of actinide analyses and biokinetic research. WSU Department of Chemistry Research Seminar, Pullman, WA, October 26, 2018.

USTUR-0517-19P

Tolmachev SY. Radioactive actinide particles in occupationally exposed individuals. Podium presentation at the Centre for Environmental Radioactivity Workshop on Health Effects Following Severe Nuclear Events, Oslo, Norway, February 3, 2019.

USTUR-0518-19P

Tolmachev SY. Bioimaging of samples from the United States Transuranium and Uranium Registries - Shedding new light on the biokinetics, dosimetry, and possible biological effects of actinides in humans. Invited presentation at the Centre for Environmental Radioactivity Workshop on Particle Characteristics and Nuclear Forensics, Oslo, Norway, February 5, 2019.

Podium

USTUR-0497-18A

Dumit S, Strom DJ, McComish SL, Avtandilashvili M, Tabatadze G, Tolmachev SY. New biokinetic model simultaneously fits Ca-DTPA affected and non-affected urine bioassay data after plutonium contamination. Podium presentation at the 63rd

Health Physics Society Annual Meeting, Cleveland, OH, July 15 – 19, 2018.

USTUR-0497-18A

Strom DJ. A simple visualization of the LEKSKaM 2005 model of systemic plutonium biokinetics. Podium presentation at the 63rd Health Physics Society Annual Meeting, Cleveland, OH, July 15 – 19, 2018.

USTUR-0507-18A

Avtandilashvili M, Tolmachev SY. Biokinetics of soluble plutonium after wound injury treated with Ca-DTPA. Podium presentation at the 12th International Conference on Health Effects of Incorporated Radionuclides, Fontenay-aux-Roses, France, October 8 – 11, 2018.

USTUR-0508-18A

Tolmachev SY, McComish SL, Avtandilashvili M. USTUR: Expanding horizons for actinide biokinetics and dosimetry. Podium presentation at the 12th International Conference on Health Effects of Incorporated Radionuclides, Fontenay-aux-Roses, France, October 8 – 11, 2018.

USTUR-0509-18A

Leggett R, Tolmachev SY, Boice J. Case studies in brain dosimetry for internal emitters: Is more biokinetic detail needed for epidemiology? Podium presentation at the 12th International Conference on Health Effects of Incorporated Radionuclides, Fontenay-aux-Roses, France, October 8 – 11, 2018.

Poster

USTUR-0512-19A

Dumit S, Strom DJ, McComish SL, Avtandilashvili M, Tabatadze G, Tolmachev SY. New biokinetic model simultaneously fits Ca-DTPA affected and non-affected urine bioassay data after plutonium contamination. Poster presentation at the Brazilian Graduate Student Conference (BRASCON), Columbus, OH, June 23 – 24, 2018.

USTUR-0503-18A

Avtandilashvili M, Tolmachev SY. Four decade follow up of plutonium contaminated puncture wound treated with Ca-DTPA. Poster presentation at the Conference on Radiation and Health, Chicago, IL, September 23 – 25, 2018.

USTUR-0499-18A

Zhou J, McComish SL, Tolmachev SY. Update on causes of death among 353 former nuclear workers in the United States Transuranium and Uranium Registries. Poster presentation at the 64th Annual Meeting of Radiation Research Society, Chicago, IL, September 23 – 26, 2018.

USTUR-0504-18A

Dumit S, Avtandilashvili M, Strom DJ, McComish SL, Tabatadze G, Tolmachev SY. New compartmental model for plutonium decorporation therapy. Poster presentation at the 64th Annual Meeting of Radiation Research Society, Chicago, IL, September 23 – 26, 2018.

USTUR Bibliographic Metrics

Stacey L. McComish, *Associate in Research*

Since its inception in 1968, the USTUR has published 225 papers in conference proceedings and peer-reviewed journals, 17 books/book sections, 82 abstracts in journals, and 13 miscellaneous journal publications such as letters to the editor. These publications were authored by USTUR staff, SAC members, and/or emeritus/adjunct faculty.

USTUR publications have appeared in 49 different journals, with a highest impact factor of 8.378 (Cancer Research). Five journals account for 85% of published peer-reviewed papers: Health Physics (0.993), Radiation Protection Dosimetry (0.831), the Journal of Radioanalytical and Nuclear Chemistry (1.186), Radiation Research (2.779), and the International Journal of Radiation Biology (2.266).

The USTUR's publications profile was tracked on-line through the Publons bibliographic service. Publons generates citation metrics for articles in the Web of Science collection. Of the USTUR's 337 publications, 262 had citation data. These articles were cited 3,524 times, and the USTUR has an h-index of 30. It is clear from these numbers that the USTUR's research continues to have an important impact on our understanding of actinides in humans. Figure 14 displays the number of USTUR journal articles published per year, and number of times articles were cited each year. To explore the USTUR's publications on Publons, visit:

https://publons.com/researcher/2623846/ustur-cpps-wsu/.

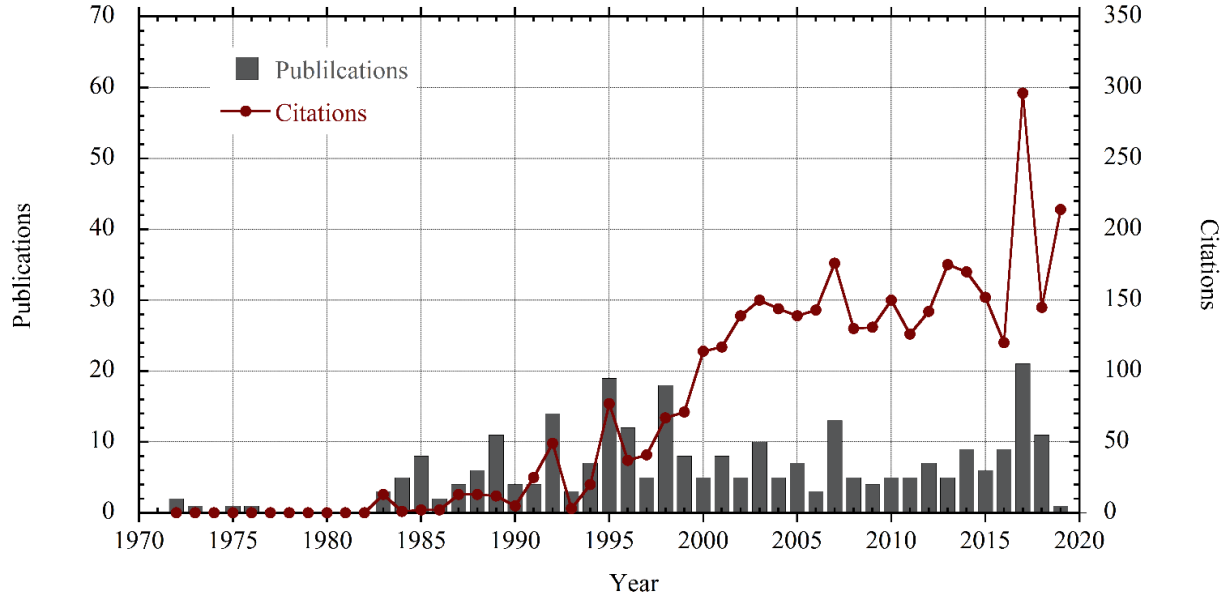


Fig 14. The number of USTUR publications per year, and the number of times articles were cited in each year.

Appendix A

Department of Energy
Washington, DC 20585

April 23, 2018

Sergei Y. Tolmachev, PhD
Director, United States Transuranium and
Uranium Registries
College of Pharmacy, Washington State University
1845 Terminal Drive, Suite 201
Richland, Washington 99354-4959

Dear Dr. Tolmachev:

The year 2018 marks the 50th anniversary of the United States Transuranium and Uranium Registries (USTUR). The Department of Energy takes pride in supporting the longest domestic radiation health study in the United States. We are celebrating together five decades of the USTUR achievements in radionuclides research and radiation protection. We thank you and your team for your dedication and contribution to the program.

The USTUR is considered a global resource and premier program to study the deposition and movement of radioactive materials through the human body following accidental intakes. Since its inception in 1968, USTUR scientists have contributed significantly to the field of health physics and radiological sciences. The USTUR has made real impact in providing scientific basis for radiation protection standards.

The USTUR has made significant progress, and collaborative research projects have been expanded both domestically and internationally. The radiochemistry and health physics databases have been enriched and refined to better support research not only in the field of internal radiation dosimetry, but also in therapeutic removal of radionuclides, bio-dosimetry, and nuclear forensics. We are looking forward to the publication of the upcoming special issue of the *Health Physics* Journal featuring 11 scientific papers on USTUR's latest research findings.

The Nation owes a great deal of debt to the former nuclear workers who, as volunteer Registrants, continued to serve their country in the cause of advancing science. Their ultimate sacrifice, along with that of their loved ones honoring their wishes, has enabled USTUR to obtain, preserve, and make available for future research samples of tissues at autopsy. Because of their selfless acts, the scientists are able to develop more reliable epidemiological studies, more

2

accurately project risks, and ultimately better protect the safety and health of current and future generations of nuclear workers through more effective standards for radiological protection. Their contribution and the difference they have made will not be forgotten.

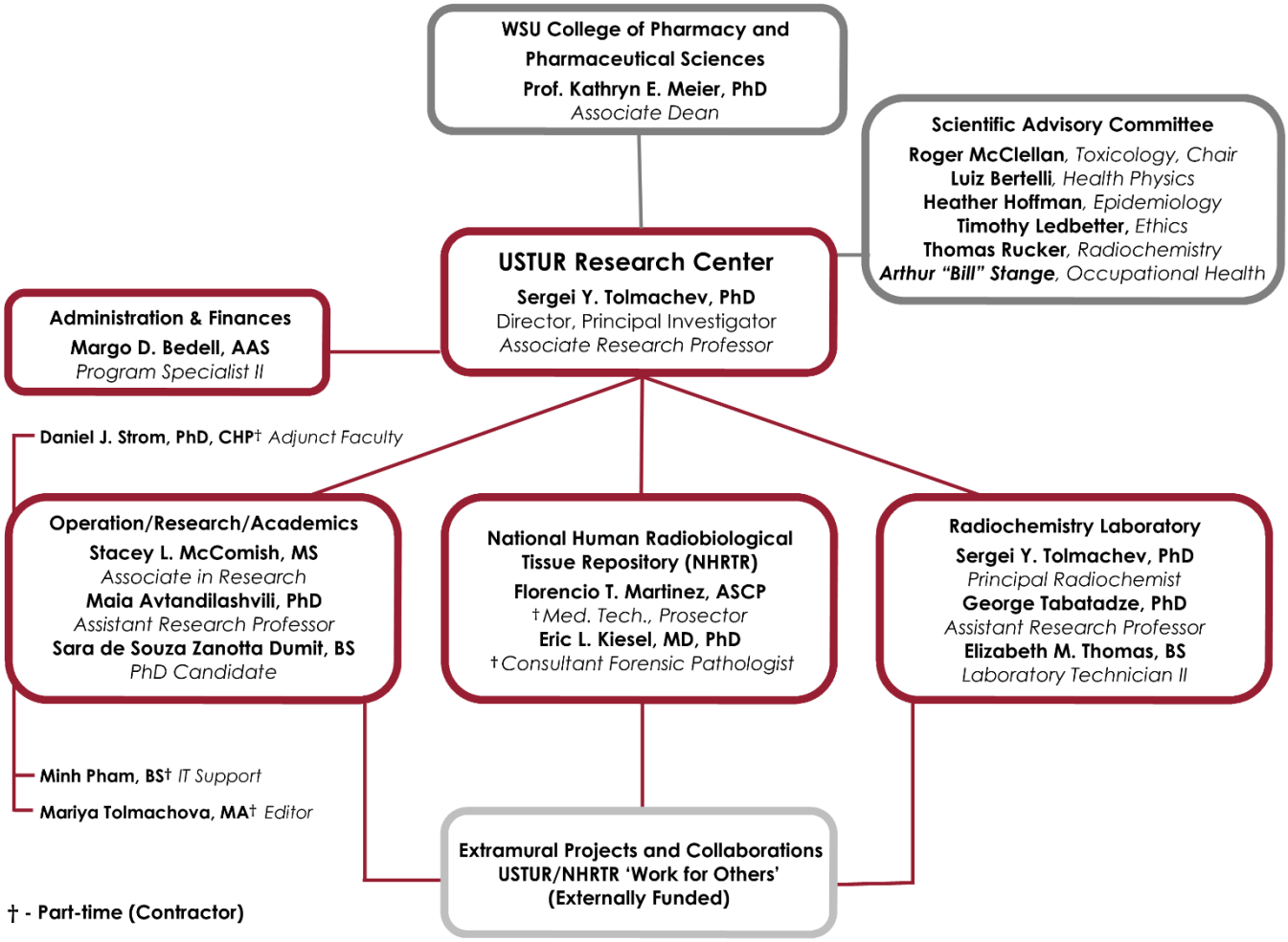
We wish you and the USTUR continued success.

Sincerely,

MB Moury

Matthew B. Moury
Associate Under Secretary for
Environment, Health, Safety and Security

Appendix B



USTUR Research Center organization structure during FY2019.

Appendix C

NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

President: John D. Boice, Jr.; *Senior Vice President*: Jerrold T. Bushberg; *Executive Director*: Kathryn D. Held
7910 Woodmont Avenue, Suite 400, Bethesda, Maryland 20814-3095 Voice: (301) 657-2652 Fax: (301) 907-8768

May 10, 2018

Maia Avtandilashvili, PhD
U.S. Transuranium and Uranium Registries
College of Pharmacy, Washington State University
1845 Terminal Drive, Suite 201
Richland, WA 99354
m.avtandilashvili@wsu.edu

Dear Dr. Avtandilashvili:

I am pleased to inform you that the NCRP Board of Directors approved your appointment as a member of the new NCRP Scientific Committee 6-12 (SC 6-12) charged with preparing a commentary that describes new approaches to obtain dose to the brain following intakes of radionuclides. This will help ongoing efforts with regard to DOE and other grants focusing on the effects of high-LET particles in the brain, as well as provide new knowledge on brain dosimetry relevant to protection that is not heretofore available.

Please confirm your willingness to serve on the committee by completing the attached form and returning it to Ms. Laura Atwell, the NCRP Office Manager, by e-mail (atwell@ncrponline.org).

Enclosed is a copy of NCRP's Conflict of Interest policy. By signing the form agreeing to serve on Scientific Committee 6-12, you will also be verifying that you do not have any conflict of interest resulting from this appointment.

If you have any questions please contact me at (boice@ncrponline.org) or by phone at 301-657-2652 ext. 19.

Sincerely yours,

John D. Boice, Jr.

John D. Boice, Jr.
President

NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

President: John D. Boice, Jr.; *Senior Vice President*: Jerrold T. Bushberg; *Executive Director*: Kathryn D. Held
7910 Woodmont Avenue, Suite 400, Bethesda, Maryland 20814-3095 Voice: (301) 657-2652 Fax: (301) 907-8768

May 10, 2018

Sergei Y. Tolmachev Ph.D.
Associate Research Professor (Radiochemistry)
Washington State University
U.S. Transuranium and Uranium Registries
1845 Terminal Drive
Suite 201
Richland, WA 99354-4959
stolmachev@wsu.edu

Dear Dr. Tolmachev:

I am pleased to inform you that the NCRP Board of Directors approved your appointment as Vice Chairman of the NCRP Scientific Committee 6-12 (SC 6-12) charged with preparing a commentary that describes new approaches to obtain dose to the brain following intakes of radionuclides. This will help ongoing efforts with regard to DOE and other grants focusing on the effects of high-LET particles in the brain, as well as provide new knowledge on brain dosimetry relevant to protection that is not heretofore available.

Please confirm your willingness to serve on the committee by completing the attached form and returning it to Ms. Laura Atwell, the NCRP Office Manager, by e-mail (atwell@ncrponline.org).

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If you have any questions please contact me at (boice@ncrponline.org) or by phone at 301-657-2652 ext. 19.

Sincerely yours,

John D. Boice, Jr.

John D. Boice, Jr.
President

Appendix D

Memorandum of Understanding (MOU)
Between
Washington State University, Pullman, WA, USA
And
The Centre for Radiation Chemical and Environmental Hazards, Oxfordshire, UNITED KINGDOM

ARTICLE I. PARTIES AND PURPOSE

The Centre for Radiation Chemical and Environmental Hazards (CRCE) and Washington State University (WSU) by and through its United States Transuranium and Uranium Registries conduct programs and activities of basic and applied research, education and training, technology and information transfer, and economic development. CRCE and WSU have capabilities and expertise in conducting programs and activities of interest and potential benefit to the other.

CRCE and WSU will cooperate in efforts to establish and conduct mutually agreed upon cooperative and collaborative projects, programs, and/or activities, which will enhance the programs of each. Specific details of any cooperative/collaborative activities to be conducted, including cooperation with third parties and allocation of support and resources, shall be set forth and agreed upon in writing as a contract between parties.

This MOU also recognizes there is a separate End User Licence Agreement as signed on December 5, 2018.

ARTICLE II. COOPERATION WITH THIRD PARTIES

Since other universities, institutes, centers and organizations may have capabilities and conduct activities, which will benefit and support this collaboration, CRCE and WSU may identify other cooperators for joint participation in mutually agreed upon projects and activities.

ARTICLE III. DURATION, TERMINATION

The parties shall cooperate under this MOU for an initial period of five (5) years from the date of last signature, which may be extended by the mutual written consent of the parties. This MOU may be terminated by either party without liability at any time for any reason. Any modification shall require the written approval of the signature authority of Washington State University and the signature authority of The Centre for Radiation Chemical and Environmental Hazards, or their designees.

ARTICLE IV. NON-BINDING NATURE

This MOU is intended only to set forth the general understanding of the parties with respect to the subject matter herein, and does not, and is not intended to, contractually bind the parties.

ARTICLE V. RESOLUTION OF DISPUTES

In the event that a dispute arises under this MOU, the parties shall make every effort to resolve it themselves. Should the parties enter future contracts contemplated by this MOU, such contracts will contain a detailed resolution process.

ARTICLE VI. CONTACT PERSONS

The Centre for Radiation Chemical and Environmental Hazards

David Rhodes
Centre Director
Public Health England, Chilton Didcot
Oxfordshire OX11 ORQ, UNITED KINGDOM
Phone: 44 (0) 1235 831600
E-mail: david.rhodes@phe.gov.uk
Website: https://www.phe-protectionservices.org.uk/rpa/contact/locations

Anthony Riddell
Internal Dosimetry Group Leader
Public Health England, Chilton Didcot
Oxfordshire OX11 ORQ, UNITED KINGDOM
Phone: 44 (0) 1235 825036
E-mail: tony.riddell@phe.gov.uk

Washington State University

Dr. Asif Chaudhry
Vice President for International Programs
PO Box 645121, Bryan Hall 301
Pullman, WA 99164-5121
Phone: 509-335-2541
Fax: 509-335-2982
E-mail: ip.admin@wsu.edu
Website: https://ip.wsu.edu/

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Website: https://www.phe-protectionservices.org.uk/rpa/contact/locations

ARTICLE VII. SIGNATURES

The Centre for Radiation Chemical and Environmental Hazards

Approved by:

15/2/2019

David Rhodes — Date
Centre Director

18/2/2019

Anthony Riddell — Date
Internal Dosimetry Group Leader

Washington State University

Approved by:

12/17/2018

Dr. Asif Chaudhry — Date
Vice President for International Programs

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Appendix E

ISSUE 24 • 2018 • USTUR-0510-18

USTUR Newsletter

From the Director's Desk

Dear Registrants and Families:

It is my pleasure to have this opportunity to tell you about the USTUR's activities and achievements in 2018 – the 50th year since its establishment.

On April 23rd, the Registries received a letter of commendation from the Department of Energy Headquarters signed by Matthew B. Moury (Associate Under Secretary for Environment, Health, Safety and Security), which recognized that "the Nation owes a great deal of debt to the former nuclear workers who, as volunteer Registrants, continued to serve their country in the cause of advancing science. Their ultimate sacrifice, along with that of their loved ones honoring their wishes, has enabled USTUR to obtain, preserve, and make available for future research samples of tissues at autopsy. Because of their selfless acts, the scientists are able to develop more reliable epidemiological studies, more accurately project risks, and ultimately better protect the safety and health of current and future generations of nuclear workers through more effective standards for radiological protection. Their contribution and the difference they have made will not be forgotten". I can't say it better than Mr. Moury: your contributions to the Registries are important and valued!

I would also like to introduce the new members of the Scientific Advisory Committee (SAC) that came on board during the past year. Dr. Luiz Bertelli from Los Alamos National Laboratory (LANL) and Dr. Arthur (Bill) Stange from Oak Ridge Associated Universities (ORAU) joined the SAC as Health Physics and Occupational Health representatives, respectively. Some of you might know or even have interacted with Dr. Stange as he has provided epidemiological oversight and analysis of medical surveillance findings for the DOE Rocky Flats Plant Beryllium Medical Surveillance Program and the ORAU's Nationwide Beryllium Medical Surveillance Program.

Inside this issue are details about just a few of the Registries' 50-year achievements and discoveries. Our gratitude goes out to you and we wish you a happy holiday season!

50 Years

Learning from Plutonium and Uranium Workers


USAEC (DBM) Meeting on "Plutonium Contamination in Man"
July 25-26, 1966, Denver (Rocky Flats Plant)

1966: Details of the proposed plutonium registry began to take form during informal discussions and two larger meetings held at the Rocky Flats Plant in 1966 and Lovelace in 1967. According to H.D. Bruner of the Atomic Energy Commission, **"the idea of a Registry occurred to many men about the same time."** The National Plutonium Registry, a predecessor to the USTUR, was **founded in 1968**.

356 Registrant donations

Male: 344 Female: 12

33 U.S. states

333 Papers published

Early on, there were two separate registries: the U.S. *Transuranium* Registry (aka National Plutonium Registry, founded 1968) and the U.S. *Uranium* Registry (1972). These combined in **1992 to form the U.S. Transuranium and Uranium Registries**.

At about the same time, Argonne National Laboratory transferred tissues from the **historical radium dial painter studies** to the USTUR, forming the National Human Radiobiological Tissue Repository. In 2016, radiation-induced changes to a type of white blood cell, called a lymphocyte, were identified in blood from radium dial painters that was preserved on slides in the 1970s. The findings are important scientifically, and because they highlight the importance of saving tissue materials for future research.

Commendation from DOE Associate Under Secretary

2018: Department of Energy's (DOE) Associate Under Secretary for Environment, Health, Safety and Security – Matthew Moury – applauded the USTUR with a letter recognizing the **USTUR's role in providing a scientific basis for radiation protection standards**. The USTUR is the longest-running domestic radiation health study in the United States. The letter highlights recent research, thanks the USTUR team for its dedication to the program, and expresses **a deep sense of gratitude for Registrants and their families**.

Educating the Next Generation

A unique way that USTUR research protects future radiation workers is through its role in educating the next generation of radiation protection professionals, who will be responsible for protecting workers.

Since the USTUR moved to WSU in 1992, sixteen graduate students have used USTUR data to complete the research requirement of their studies. Several of our more recent graduates have focused on what we call biokinetic modeling. Biokinetic models are mathematical models that describe the movement of plutonium (and other radionuclides) through the human body. Students gain not only a thorough understanding of the models that are used to calculate doses for workers, but they have the opportunity to work with real data, such as lung counts and the amount of plutonium excreted in urine. Real data present the students with real-world challenges that shape them into professionals who are better prepared to address the unique exposure scenarios that future workers may encounter.

Our most recent graduate is Sara Dumit. Dr. Dumit developed a new mathematical model to describe the removal of plutonium from the human body during treatment with special drugs, called chelating agents. Chelating agents are sometimes given to workers who have inhaled plutonium, or taken it into their bodies through another route, such as a contaminated wound. Chelating agents remove plutonium from the body by binding to the plutonium and turning it into a chemical form that is readily excreted in urine. Dr. Dumit's doctoral dissertation titled, "Development of a New Compartmental Model for Plutonium Decorporation Therapy" was successfully defended May 14, 2018, and in August, she joined the Los Alamos National Laboratory's internal dosimetry team as a post-doctoral researcher. A paper describing the structure of her model was published ahead of print by the Health Physics journal in 2018.

Sara Dumit and her graduate committee: Sayed Daoud, Kathryn E. Meier, Sergei Tolmachev, Jeannie Padowski, Daniel Strom.

PAST STUDENTS

8 Doctoral

8 Master's

Two former students are now research professors right here at the USTUR. Others are employed by institutions such as The National Institute for Occupational Safety and Health (NIOSH), Los Alamos National Laboratory, HPMC Occupational Medical Services, and Bloomsburg University.

Medical Screening

You may be eligible for medical screening through the Department of Energy's Former Worker Medical Screening Program. We mentioned this program to you a couple years ago, and recently we received detailed brochures, which we would like to share with you. Please see the enclosed National Supplemental Screen Program brochure to learn more.

Kathrens donate radiological book collection


Ronald and Susan Kathren

Former USTUR director and WSU professor emeritus, Ronald Kathren, and his wife, Susan, donated an extensive collection of radiological books to WSU Tri-Cities. The collection covers topics relevant to radiological sciences, and is available to WSU students and faculty, as well as professionals and members of the public. The Ronald and Susan Kathren Radiological and Affiliated Sciences Collection was dedicated during a ceremony on May 18th. Kathren directed the Registries from 1989 until 1999, and transferred the program from the Hanford Environmental Health Foundation (HEHF) to WSU in 1992.

United States Transuranium and Uranium Registries

College of Pharmacy and
Pharmaceutical Sciences
Washington State University
1845 Terminal Dr., Suite 201
Richland, WA 99354
509-946-6870
509-946-7972 Fax

For more information call 800-375-9317 or visit us online at www.ustur.wsu.edu


Maia Avtandilashvili, Margo Bedell, Sara Dumit, Sergei Tolmachev, Stacey McComish, George Tabatadze, Elizabeth Thomas

Appendix F

UNITED STATES TRANSURANIUM AND URANIUM REGISTRIES

College of Pharmacy, Washington State University

2018 Scientific Advisory Committee Meeting

Hampton Inn, Richland, WA, April 26 – 27, 2018

Thursday, April 26, 2018

07:45 – 08:30	***Breakfast***	
08:30 – 08:40	Welcome & Introductions	S. Tolmachev, *USTUR Director*
08:40 – 8:50	WSU/COP News	K. Meier, *Associate Dean*
08:50 – 09:00	Updates from DOE/AU-13. Guidance for FY2018	J. Zhou, *DOE Manager*
09:00 – 09:15	Introducing a new SAC member	L. Bertelli, *LANL*
09:15 – 09:30	Administrative & Financial Developments	M. Bedell, *Program Specialist*
09:30 – 10:15	2017 SAC Recommendations & 2018 USTUR Overview	S. Tolmachev, *Director*
10:15 – 10:45	***Coffee Break***	
10:45 – 11:00	USTUR Registrant Statistics	S. McComish, *Associate in Research*
11:00 – 11:15	Health Physics Database Progress Report	M. Avtandilashvili, *Assist. Res. Professor*
11:15 – 11:30	National Human Radiobiological Tissue Repository	S. McComish, *Associate in Research*
11:30 – 12:00	Radiochemistry Progress Report	G. Tabatadze, *Assist. Res. Professor*
12:00 – 13:30	***Lunch***	
13:30 – 13:55	New Plutonium Decorporation Model	S. Dumit, *PhD Candidate*
13:55 – 14:25	Internal Dosimetry Software Development at PHE	A. Riddell, *PHE (UK)*
14:25 – 14:45	Research at University of Missouri Research Reactor Center	J. Brockman, *Assoc. Res. Prof., MURR*
14:45 – 15:05	Operation & Research at WSU Nuclear Science Center	D. Wall, *WSU NSC Director*
15:05 – 15:30	***Coffee Break***	
15:30 – 16:00	Research & Operation: Plan for FY2019	S. Tolmachev, *Director*
16:00 – 16:30	Discussion and Q & A	USTUR, DOE, SAC, Guests

18:00 – 21:00 *Dinner -- at Taverna Tagaris, 844 Tulip Lane, Richland, WA*

Meetings, breakfast, and lunch will be held in the Riverview Room at the Hampton Inn, 486 Bradley Blvd, Richland, WA

UNITED STATES TRANSURANIUM AND URANIUM REGISTRIES

College of Pharmacy, Washington State University

2018 Scientific Advisory Committee Meeting

Hampton Inn, Richland, WA, April 26 – 27, 2018

Friday, April 27, 2018 – SAC, DOE and USTUR Management

08:00 – 09:00	***Breakfast***	
09:00 – 09:10	SAC Membership	S. Tolmachev, *USTUR Director*
09:10– 09:45	SAC Q & A	R. McClellan, *SAC Chair*
9:45 – 12:30	SAC Executive Session	R. McClellan, *SAC Chair*
9:45 – 12:30	*Tour to USTUR Laboratory Facility, Richland Airport*	*USTUR/Guests*
12:30 – 13:30	***Lunch***	
13:30 – 15:30	SAC Debriefing	R. McClellan, *SAC Chair*

Friday, April 27, 2018 – All

18:30 – 21:00	*Dinner/Buffet – Hanford REACH Museum Venue, 1943 Columbia Park Trail, Richland, WA*

Appendix G

USTUR-0472-17

Improved modeling of plutonium-DTPA decorporation

S. Dumit, M. Avtandilashvili, D. J. Strom, S. L. McComish, G. Tabatadze, S. Y. Tolmachev

United States Transuranium and Uranium Registries, Washington State University, Richland, WA, USA

Individuals with significant intakes of plutonium (Pu) are typically treated with chelating agents, such as the trisodium salt form of calcium diethylenetriaminepentaacetate ($CaNa_3$-DTPA, referred to hereafter as Ca-DTPA). Currently, there is no recommended approach for simultaneously modeling plutonium biokinetics during and after chelation therapy. In this study, an improved modeling system for plutonium decorporation was developed. The system comprises three individual model structures describing, separately, the distinct biokinetic behaviors of systemic plutonium, intravenously injected Ca-DTPA and in vivo-formed Pu-DTPA chelate. The system was linked to ICRP Publication 100, ''Human Alimentary Tract Model for Radiological Protection'' and NCRP Report 156, Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for Their Assessment, Dosimetry and Treatment.'' Urine bioassay and chelation treatment data from an occupationally-exposed individual were used for model development. Chelation was assumed to occur in the blood, soft tissues, liver and skeleton. The coordinated network for radiation dosimetry approach to decorporation modeling was applied using a chelation constant describing the secondorder, time-dependent kinetics of the in vivo chelation reaction. When using the proposed system of models for plutonium decorporation, a significant improvement of the goodness-of-fit to the urinary excretion data was observed and more accurate predictions of postmortem plutonium retention in the skeleton, liver and wound site were achieved.

Radiation Research 191: 201-210; 2019.

USTUR-0495-18

Determination of ^{232}Th and progeny in human reticuloendothelial tissues using alpha particle track autoradiographic microdosimetry from Thorotrast

N. R. Schneider[1], T. Xie[1], S. E. Glover[1], S. Y. Tolmachev[3], Z. Dong[2], H. B. Spitz[1]

[1]*Department of Mechanical and Materials Engineering, College of Engineering, University of Cincinnati, Cincinnati, OH, USA*

[2]*Department of Hematology-Oncology, College of Medicine, University of Cincinnati, Cincinnati, OH, USA*

[3]*United States Transuranium and Uranium Registries, Washington State University, Richland, WA, USA.*

Targeted alpha therapy has the properties of direct ionization, oxygen independency, high linear energy transfer, a short half-life, and minimal depth of penetration, which are advantageous in cancer treatment. This modified, inexpensive, high-resolution, autoradiographic study of ^{232}Th decay in a tissue specimen, to both locate and quantify individual alpha-particle origins, track lengths, and dose rates, utilized conventional Ilford Pan F Plus, 135–36, Black and White, 35 mm, ISO 50 film. Dose rates measured 0.14 cGy d^{-1} in the liver, 0.03 cGy d^{-1} in the right kidney, and 0.003 cGy d^{-1} in the heart, leading to a dosimetric concern of where the final alpha-particle deposition occurs.

Journal of Radioanalytical and Nuclear Chemistry 318(1): 235-239; 2018.

USTUR-0496-18

Validation of a system of models for plutonium decorporation therapy

S. Dumit, M. Avtandilashvili, D. J. Strom, S. L. McComish, G. Tabatadze, S. Y. Tolmachev

United States Transuranium and Uranium Registries, Washington State University, Richland, WA, USA

A recently proposed system of models for plutonium decorporation (SPD) was developed using data from an individual occupationally exposed to plutonium via a wound [from United States Transuranium and Uranium Registries (USTUR) Case 0212]. The present study evaluated the SPD using chelation treatment data, urine measurements, and post-mortem plutonium activities in the skeleton and liver from USTUR Case 0269. This individual was occupationally exposed to moderately soluble plutonium via inhalation and extensively treated with chelating agents. The SPD was linked to the International Commission on Radiological Protection (ICRP) Publication 66 Human Respiratory Tract Model (HRTM) and the ICRP Publication 30 Gastrointestinal Tract model to evaluate the goodness-of-fit to the urinary excretion data and the predictions of post-mortem plutonium retention in the skeleton and liver. The goodness-of-fit was also evaluated when the SPD was linked to the ICRP Publication 130 HRTM and the ICRP Publication 100 Human Alimentary Tract Model. The present study showed that the proposed SPD was useful for fitting the entire, chelation-affected and non-affected, urine bioassay data, and for predicting the post-mortem plutonium retention in the skeleton and liver at time of death, 38.5 years after the accident. The results of this work are consistent with the conclusion that Ca-EDTA is less effective than Ca-DTPA for enhancing urinary excretion of plutonium.

Radiation and Environmental Biophysics 2019; doi: 10.1007/s00411-018-00773-y.

USTUR-0502-18

Potential improvements in brain dose estimates for internal emitters

R. W. Leggett[1], S. Y. Tolmachev[2], J. D. Boice[3,4]

[1]*Oak Ridge National Laboratory, Oak Ridge, TN, USA*
[2]*U.S. Transuranium and Uranium Registries, 1845 Terminal Dr., Suite 201, Richland, WA, USA*
[3]*National Council on Radiation Protection and Measurements, Bethesda, MD, USA*

[4]*Division of Epidemiology, Department of Medicine, Vanderbilt Epidemiology Center and Vanderbilt-Ingram Cancer Center, Nashville, TN, USA.*

BACKGROUND: Element-specific biokinetic models are used to reconstruct doses to systemic tissues from internal emitters. Typically, a systemic model for a radionuclide explicitly depicts only its dominant repositories. Remaining tissues and fluids are aggregated into a pool called Other tissue in which the radionuclide is assumed to be uniformly distributed. In the systemic biokinetic models used in radiation protection, the brain usually is addressed as an implicit mass fraction of *Other* tissue rather than an explicitly depicted repository. Due to increasing interest in radiation effects on the brain, efforts are underway to improve brain dosimetry for internal radiation sources.

METHODS: We assessed potential improvements in brain dosimetry for internal emitters by explicitly modelling brain kinetics rather than treating the brain as a mass fraction of *Other* tissue. We selected ten elements for which brain kinetics can be modeled using published biokinetic data. Injection dose coefficients were calculated for a relatively long-lived radioisotope of each element using each of two versions of the ICRP's latest systemic biokinetic model for each element, the original version and a modified version differing only in the treatment of brain. If the ICRP model contained an explicit brain pool, the modified version depicted brain instead as a mass fraction of *Other* tissue. If the ICRP model included brain in *Other* tissue, the modified version included an explicit brain pool with kinetics based on best available brain-specific data.

RESULTS: The result for a given radionuclide is expressed as a ratio A:B, where A and B are the dose coefficients based on the versions of the model with and without an explicit brain pool, respectively. The following ratios A:B were obtained for the 10 radionuclides addressed here: ^{241}Am, 0.13; ^{207}Bi, 0.57; ^{234}U, 0.81; ^{239}Pu, 0.96; ^{203}Hg (vapor), 1.4; ^{134}Cs, 1.5; ^{54}Mn, 1.7; ^{210}Po, 1.7; ^{226}Ra, 1.9; ^{210}Pb, 3.3. These ratios indicate that a dose estimate for brain based on a biokinetic model with brain implicitly contained in *Other* tissue may substantially underestimate or substantially overestimate a dose estimate that reflects best available brain-specific biokinetic data. Of course, the reliability of the latter estimate depends on the quality of the underlying biokinetic data.

CONCLUSIONS: Where feasible, the brain should be depicted explicitly in biokinetic models used in epidemiological studies addressing adverse effects of ionizing radiation.

International Journal of Radiation biology 2018, doi: 10.1080/09553002.2018.1554923.

USTUR-0435-16

USTUR Case 0846: Modeling americium biokinetics after intensive decorporation therapy

B. Breustedt[1], M. Avtandilashvili[2], S. L. McComish[2], S.Y. Tolmachev[2]

[1]*Karlsruhe Institute of Technology, Safety and Environment (SUM), Eggenstein-Lepoldshafen, Germany*
[2]*U.S. Transuranium and Uranium Registries, 1845 Terminal Dr., Suite 201, Richland, WA, USA*

Decorporation therapy with salts of diethylenetriamine-pentaacetic acid binds actinides, thereby limiting uptake to organs and enhancing the rate at which actinides are excreted in urine. International Commission on Radiological Protection reference biokinetic models cannot be used to fit this enhanced exertion simultaneously with the baseline actinide excretion rate that is observed prior to the start of therapy and/or after the effects of therapy have ceased. In this study, the Coordinated Network on Radiation Dosimetry approach, which was initially developed for modeling decorporation of plutonium, was applied to model decorporation of americium using data from a former radiation worker who agreed to donate his body to the US Transuranium and Uranium Registries for research. This individual was exposed to airborne Am, resulting in a total-body activity of 66.6 kBq. He was treated with calcium-diethylenetriamine-pentaacetic acid for 7 y. The time and duration of intakes are unknown as no incident reports are available. Modeling of different assumptions showed that an acute intake of 5-µm activity median aerodynamic diameter type M aerosols provides the most reasonable description of the available pretherapeutic data; however, the observed Am activity in the lungs at the time of death was higher than the one predicted for type M material. The Coordinated Network on Radiation Dosimetry approach for decorporation modeling was used to model the in vivo chelation process directly. It was found that the Coordinated Network on Radiation Dosimetry approach, which only considered chelation in blood and extracellular fluids, underestimated the urinary excretion of Am during diethylenetriamine-pentaacetic acid treatment; therefore, the approach was extended to include chelation in the liver. Both urinary excretion and whole-body retention could be described when it was assumed that 25% of chelation occurred in the liver, 75% occurred in the blood and ST0 compartment, and the chelation rate constant was 1×10 pmol^{-1} d^{-1}. It was observed that enhancement of urinary excretion of Am after injection of diethylenetriamine-pentaacetic acid exponentially decreased to the baseline level with an average half-time of 2.2 ± 0.7 d.

Health Physics 2018, doi: 10.1097/HP.0000000000000931.

USTUR-0432-16

Digital autoradiography of ^{241}Am spatial distribution within trabecular bone regions

G. Tabatadze[1], B. W. Miller[2,3], S.Y. Tolmachev[1]

[1]*U.S. Transuranium and Uranium Registries, College of Pharmacy, Washington State University, Richland, WA, USA*
[2]*Department of Radiation Oncology, School of Medicine, University of Colorado, Aurora, CO, USA*
[3]*College of Optical Sciences, University of Arizona, Tucson, AZ, USA*

Digital autoradiography with the ionizing radiation quantum imaging detector is used at the US Transuranium and Uranium Registries for visualizing the microdistribution of alpha particles from ^{241}Am and quantifying the activity. The radionuclide spatial distribution was investigated within cortical and trabecular regions of bone samples from US Transuranium and Uranium Registries Case 0846. Multiple specimens from the humerus proximal end, humerus proximal shaft, and clavicle acromial end were embedded in plastic, and 100-µm-thick

sections were taken and imaged using the ionizing radiation quantum imaging detector. The detector images were superimposed on the anatomical structure images to visualize ^{241}Am distribution in cortical bone, trabecular bone, and trabecular spongiosa. Activity concentration ratios were used to characterize ^{241}Am distribution within different bone regions. The trabecular-to-cortical bone and trabecular-spongiosa-to-cortical bone activity concentration ratios were quantified in both humerus and clavicle. The ionizing radiation quantum imaging detector results were in agreement with those obtained from radiochemical analysis of the remaining bone specimens. The results were compared with International Commission on Radiological Protection default biokinetic model predictions. Digital autoradiography was proven to be an effective method for microscale heterogeneous distribution studies where traditional counting methods are impractical.

Health Physics 2018, doi: 10.1097/HP.0000000000000947.

USTUR-0427-16

The United States Transuranium and Uranium Registries (USTUR): A five decade follow-up of plutonium and uranium workers

R. L. Kathren, S.Y. Tolmachev

U.S. Transuranium and Uranium Registries, College of Pharmacy, Washington State University, Richland, WA, USA

Dedication: The research of the US Transuranium and Uranium Registries relies heavily upon postmortem autopsy findings and radiochemical analysis of tissues. The enormous debt owed to those now-deceased registrants who unselfishly voluntarily participated in the US Transuranium and Uranium Registries program through postmortem donation of their tissues and to those still-living registrants who have volunteered to be future postmortem tissue donors is hereby acknowledged with gratitude. The scientific findings derived from postmortem analysis of these tissues have been instrumental in advancing our understanding of the actinide elements in humans and have led to refinement, validation, and confidence in safety standards for those who work with these elements as well as for the general public. To these generous and anonymous persons who made this ultimate contribution, this paper is dedicated with great thanks and admiration.

Health Physics 2018, doi: 10.1097/HP.0000000000000963.

USTUR-0430-16

Modeling skeleton weight of an adult Caucasian man

M. Avtandilashvili, S.Y. Tolmachev

U.S. Transuranium and Uranium Registries, College of Pharmacy, Washington State University, Richland, WA, USA

The reference value for the skeleton weight of an adult male (10.5 kg) recommended by the International Commission on Radiological Protection in Publication 70 is based on weights of dissected skeletons from 44 individuals, including two US Transuranium and Uranium Registries whole-body donors. The International

Commission on Radiological Protection analysis of anatomical data from 31 individuals with known values of body height demonstrated significant correlation between skeleton weight and body height. The corresponding regression equation, W_{skel} (kg) = −10.7 + 0.119 × H(cm), published in International Commission on Radiological Protection Publication 70 is typically used to estimate the skeleton weight from body height. Currently, the US Transuranium and Uranium Registries holds data on individual bone weights from a total of 40 male whole-body donors, which has provided a unique opportunity to update the International Commission on Radiological Protection skeleton weight vs. body height equation. The original International Commission on Radiological Protection Publication 70 and the new US Transuranium and Uranium Registries data were combined in a set of 69 data points representing a group of 33- to 95-y-old individuals with body heights and skeleton weights ranging from 155 to 188 cm and 6.5 to 13.4 kg, respectively. Data were fitted with a linear least-squares regression. A significant correlation between the two parameters was observed (r^2 = 0.28), and an updated skeleton weight vs. body height equation was derived: W_{skel} (kg) = −6.5 + 0.093 × H(cm). In addition, a correlation of skeleton weight with multiple variables including body height, body weight, and age was evaluated using multiple regression analysis, and a corresponding fit equation was derived: W_{skel} (kg) = −0.25 + 0.046 × H(cm) + 0.036 × W_{body} (kg) − 0.012 × A (y). These equations will be used to estimate skeleton weights and, ultimately, total skeletal actinide activities for biokinetic modeling of US Transuranium and Uranium Registries partial-body donation cases.

Health Physics 2018, doi: 10.1097/HP.0000000000000881.

USTUR-0431-16

Evaluating plutonium intake and radiation dose following extensive chelation treatment

S. Dumit, M. Avtandilashvili, S.Y. Tolmachev

U.S. Transuranium and Uranium Registries, College of Pharmacy, Washington State University, Richland, WA, USA

A voluntary partial-body donor (US Transuranium and Uranium Registries case 0785) was accidentally exposed to 239Pu via inhalation and wounds. This individual underwent medical treatment including wound excision and extensive chelation treatment with calcium ethylenediaminetetraacetic acid and calcium diethylenetriaminepentaacetic acid. Approximately 2.2 kBq of ^{239}Pu was measured in the wound site 44 y after the accident. Major soft tissues and selected bones were collected at autopsy and radiochemically analyzed for ^{238}Pu, ^{239}Pu, and ^{241}Am. Postmortem systemic retention of ^{238}Pu, ^{239}Pu, and ^{241}Am was estimated to be 32.0 ± 1.4 Bq, 2,172 ± 70 Bq, and 394 ± 15 Bq, respectively. Approximately 3% of ^{239}Pu whole-body activity was still retained in the lungs 51 y after the accident indicating exposure to insoluble plutonium material. To estimate the intake and calculate radiation dose, urine measurements not affected by chelation treatment, in vivo chest counts, and postmortem radiochemical analysis data were simultaneously fitted using Integrated Modules for Bioassay Analysis Professional Plus software. The currently recommended International Commission on Radiological Protection Publication 130 human respiratory tract model and National Council on Radiation

Protection and Measurements Report 156 wound model were used with default parameters. The intake, adjusted for ^{239}Pu removed by chelation treatment, was estimated at approximately 79.5 kBq with 68% resulting from inhalation and 32% from the wound. Inhaled plutonium was predominantly insoluble type S material (74%) with insoluble plutonium fragments deposited in the wound. Only 1.3% reduction in radiation dose was achieved by chelation treatment. The committed effective dose was calculated to be 1.49 Sv. Using urine data available for this case, the effect of chelation therapy was evaluated. Urinary excretion enhancement factors were calculated as 83 ± 52 and 38 ± 17 for initial and delayed calcium ethylenediaminetetraacetic acid treatments, respectively, and as 18 ± 5 for delayed calcium diethylenetriaminepentaacetic acid. The enhancement factor decreases proportionally to an inverse cubic root of time after intake. For delayed calcium ethylenediaminetetraacetic acid treatment, with five consecutive daily administrations, the enhancement factor increased from day 1 to 4, followed by approximately a 50% drop on day 5. The half-time of plutonium ethylenediaminetetraacetic acid complex removal in urine was evaluated to be 1.4 d.

Health Physics 2018, doi: 10.1097/HP.0000000000000882.

USTUR-0497-18A

New biokinetic model simultaneously fits Ca-DTPA affected and non-affected urine bioassay data after plutonium contamination

S. Dumit, D. J. Strom, S. L. McComish, M. Avtandilashvili, G. Tabatadze, S. Y. Tolmachev

United States Transuranium and Uranium Registries, Washington State University, Richland, WA, USA

Individuals with significant internal deposition of plutonium typically undergo medical treatment with chelating agents to enhance decorporation. The trisodium salt form of calcium diethylenetriaminepentaacetate (Ca-DTPA) is a commonly used decorporation drug that forms stable complexes with plutonium in vivo, enhancing its excretion in urine. Since plutonium biokinetics (absorption, distribution, retention, and excretion) are strongly altered by its complexation with the chelating agent, standard models cannot be used directly to estimate the radionuclide intake. Prior to this work, only empirical descriptions and ad hoc models and approaches were available to model data affected by chelation treatment. In this study, a new model that describes plutonium biokinetics during and following chelation therapy was developed, parameterized, and validated. A USTUR whole-body donor (Case 0212) was selected for this study. This individual was exposed to plutonium as a result of an occupational wound injury and underwent extensive treatment with Ca-DTPA. Urinary excretion measurements and post-mortem plutonium activities in the liver and the skeleton were used for model development and validation, respectively. The new model (linked with the Leggett et al. Plutonium Systemic Model, the ICRP 100 Human Alimentary Tract Model, and the NCRP 156 Wound Model) was implemented in SAAM II® software. The Coordinated Network for Radiation Dosimetry (CONRAD) approach to biokinetic modeling of decorporation therapy was applied by using a chelation constant to describe the kinetics of the in vivo chelation process. The new assumptions and parameters account for both the

intravenously injected Ca-DTPA and the in vivo formed Pu-DTPA chelate. The new model structure was also tested with the ICRP 67 and the Luciani and Polig Plutonium Systemic Models. The fitting of urinary excretion and autopsy data using the new model was compared to the original CONRAD Model and its optimized version, resulting in both improved goodness-of-fit to the bioassay data by order of magnitude and more accurate predictions of post-mortem plutonium retention in major depository sites.

(Abstract) *Health Physics* 2018, 115 (1 Suppl): S83.

USTUR-0498-18A

A simple visualization of the LEKSKaM 2005 model of systemic plutonium biokinetics

D. J. Strom

United States Transuranium and Uranium Registries, Washington State University, Richland, WA, USA

In 2005, Leggett, Eckerman, Khokhryakov, Suslova, Krahenbuhl, and Miller (LEKSKaM) published a revision to the 1993 ICRP Publication 67 systemic biokinetic model for plutonium. Using data from plutonium workers in the former Soviet Union and Russian Federation, the model added a second blood compartment to mathematically deal with recycling. The resultant model is somewhat difficult to grasp conceptually, since one blood compartment is depicted inside another, necessitating pathways crossing compartment boundaries. Also, arrows in the model go in all directions. In an effort to develop a more intuitive representation of the model, an alternative view is presented. The visualization is a 2-dimensional surface projected in 3 dimensions onto the surface of a cylinder, emphasizing the recycling nature of the model. With uptake to Blood 1 shown at the top, excretion pathways shown at the bottom, and recycling going from left to right, all arrows go down or to the right. The Intake compartment is shown explicitly. The Skeleton, "Other" Kidney, Gonads, Soft Tissue 1 and 2, and Liver take plutonium up from Blood 1 and gradually return it to Blood 2. The Intake Compartment, Renal Tubules, Urinary Bladder Contents, Small Intestine Contents, and Upper Large Intestine Contents are seen to be outside of the recycling part of the model. The unusual nature of ST0 (rapid turnover soft tissue) is clear. While there is no new science in this visualization, the flow of plutonium in the system is more easily comprehended. In principle, such visualizations can be made of all recycling models.

(Abstract) *Health Physics* 2018, 115 (1 Suppl): S82-S83.