USTUR-0632-22

United States Transuranium and Uranium Registries

Annual Report

April 1, 2021 – March 31, 2022

College of
Pharmacy and
Pharmaceutical Sciences
WASHINGTON STATE UNIVERSITY

USTUR-0632-22

United States Transuranium and Uranium Registries

Annual Report

April 1, 2021 – March 31, 2022

Compiled and Edited

S. Y. Tolmachev, S. L. McComish, M. Avtandilashvili

September 30, 2022

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Sergei Y. Tolmachev	Director, Research Professor
Maia Avtandilashvili	Assistant Research Professor
George Tabatadze	Assistant Research Professor
Stacey L. McComish	Associate in Research
Martin Šefl	Postdoctoral Research Associate

Emeritus and Adjunct Faculty

Ronald L. Kathren	Professor, Emeritus
Anthony E. Riddell	Adjunct Faculty
Daniel J. Strom	Adjunct Faculty

Classified Staff

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

Part-time Employees

Mark Gorelco	Professional Worker I
Florencio T. Martinez	Medical Technologist
Alexander Tabatadze	Professional Worker I

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Committee Chair

Thomas L. Rucker	Radiochemistry

Committee Members

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Luiz Bertelli	Health Physics
Timothy J. Ledbetter	Ethics
Heather J. Hoffman	Epidemiology & Biostatistics
Arthur W. Stange	Occupational Health

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Executive Summary

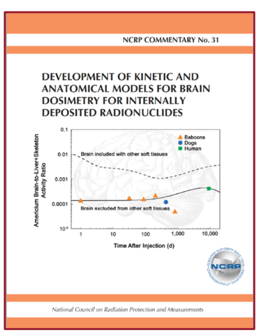
Sergei Y. Tolmachev, *Professor and Director*

This report summarizes organization, activities, and scientific accomplishments for the United States Transuranium and Uranium Registries (USTUR) and the associated National Human Radiobiology Tissue Repository (NHRTR) for the period of April 1, 2021 – March 31, 2022. This is the fifth fiscal year (FY) of the USTUR's 5-year grant proposal (FY2018–FY2022: April 1, 2017 – March 31, 2022).

Contribution to the NCRP

Commentary 31

National Council on Radiation Protection and Measurements' (NCRP) Scientific Committee (SC) 6-12 published Commentary 31: *Development of Kinetic and Anatomical Models for Brain Dosimetry for Internally Deposited Radionuclides*. Dr. Maia Avtandilashvili and Dr. Sergei Tolmachev served on the committee; Dr. Tolmachev as a vice-chair of SC 6-12, and Dr. Avtandilashvili as a member.



Scientific Committee 6-13

Dr. Avtandilashvili was appointed to serve as a member (2022–2024) of the NCRP SC 6-13: *Methods and Models for Estimating Organ Doses from Intakes of Radium*.

Anthony C. James /USTUR Scholarship

2021–2022 Anthony C. James/USTUR scholarships of $1,000 were awarded by WSU Foundation to two WSU Tri Cities undergraduate students: Robert Mcleod (Civil Engineering) and Meredith Warr (Biological Sciences). These are the third and fourth awardees since the inception of the scholarship in 2019.

Scientific Advisory Committee

The annual 2021 meeting of the USTUR's Scientific Advisory Committee was held April 8–9, 2021 by videoconference. The Committee reviewed USTUR's progress since the previous meeting (April 2020). Luiz Bertelli completed his first term as a health physics representative, and was renewed for another three-year term.

Five-year Grant Renewal

On May 31, 2021, the five-year grant renewal proposal to manage and operate the USTUR and the associated NHRTR during April 1, 2022 – March 31, 2027 (FY2023–FY2027) was submitted to the Department of Energy (DOE) Office of Health and Safety (EHSS-10) via the Office of Research Support and Operations at Washington State University (WSU). The requested FY2023–FY2027 budget was $6,500,000, with $1,200,000 to be allocated in FY2023.

Organization and Personnel

In FY2022, 7.4 full-time equivalent (FTE) positions, including one full-time postdoctoral research associate, one adjunct faculty at 0.1 FTE, and a total of 0.8 FTE for temporary professional workers, were supported by the available funding. The organizational structure of the USTUR Research Center during FY2022 is provided in Appendix A.

Registrant Donations

Three partial-body donations were received by the USTUR in FY2022. During FY2018–FY2022, the Registries received 17 donations including four whole-body cases. As of March 31, 2022, the USTUR had received 47 whole- and 317 partial-body donations.

Scholar Activities

FY2022 was very productive year for the Registries. USTUR faculty authored four and co-authored four scientific papers and an NCRP commentary. One invited talk, 13 podium presentations, and one poster presentation were given by USTUR faculty and collaborators.

During FY2018–FY2022, 51 peer-reviewed papers were published by the Registries. These include two special issues in *Radiation Protection Dosimetry* and *Health Physics* journals.

Radiochemistry Operation

Radiochemistry laboratory operation was reduced due to infrastructure upgrades. Ninety-nine tissue samples were analyzed for plutonium and americium isotopes using α-spectrometry. Radiochemical analyses of two partial-body cases were completed. During FY2018–FY2022, analyses of 1083 tissue samples from 34 cases were completed. As of March 31, 2022, the USTUR retains a backlog of 2,080 tissue samples from 19 whole- and nine partial-body cases.

Health Physics Database

Exposure records and bioassay data from 34 partial-body cases were standardized. During FY2018–FY2022, health physics data entry was completed for 95 tissue donors. As of March 31, 2022, the database holds 160,336 data records from 312 USTUR cases.

Institutional Review Board

The annual Institutional Review Board (IRB) review was completed and approved by the Central DOE IRB, and is valid until September 8, 2022.

Urine Sample Collection

Late-in-life urine sample collection was initiated for 23 living Registrants. Simulated 24-hr samples were received from 14 individuals.

Communication

The annual USTUR Newsletter (USTUR-0600-21) was sent to the Registrants and/or their next-of-kin.

Financial and Administrative Report

Margo D. Bedell, *Program Specialist II*

On March 31, 2022, the USTUR completed the fifth grant year of the USTUR's 5-year grant proposal (April 1, 2017 – March 31, 2022). The FY2022 funding was:

Federal Grant

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

Award number: DE-HS0000073.

Title: Manage and Operate the United States Transuranium and Uranium Registries.

Amount awarded: $1,200,000.

Period: April 1, 2021 – March 31, 2022.

Operating budget

Positive balance of $84,301 was reported in the end of FY2021. A total of $70,272 was carried-over to FY2022, resulting in a net operating budget of $1,270,272. Total operating expenses for FY2022 were $1,269,759 (Fig. 1).

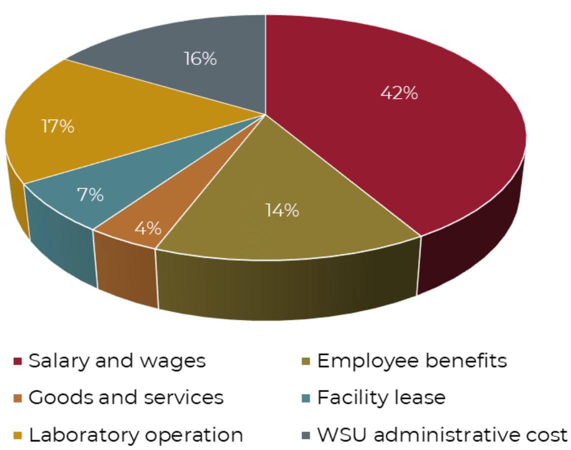


Fig. 1. FY2022 operating budget breakdown.

FY2023–FY2027 Grant Renewal

On May 31, 2021, the five-year grant renewal proposal to manage and operate the USTUR and the associated NHRTR during April 1, 2022 – March 31, 2027 (FY2023–FY2027) was submitted to the DOE/EHSS-10 via the Office of Research Support and Operations at Washington State University. The requested FY2023–FY2027 budget was $6,500,000, with $1,200,000 to be allocated in FY2023.

Reporting

The FY2021 annual report (USTUR-0587-21) for the DE-HS0000073 grant was published online: https://ustur.wsu.edu/publications/annual-reports/ and electronically distributed within the scientific community. Four quarterly reports were electronically submitted to the funding agency and the university.

IRB Changes

Stacey L. McComish, *Associate in Research*

In July 2021, the USTUR submitted minor modifications to the Central Department of Energy Institutional Review Board (CDOEIRB) as a part of the continuing review process. The submission was approved in August 2021, and the USTUR's IRB approval is valid through September 8, 2022.

Data Requests

The USTUR's recently revised communication policy, P103, was submitted to the IRB as a part of the continuing review process. The communication policy had been updated in February 2021 to reference new data request forms that were approved by the IRB in 2019. These forms allow authorized individuals to find out if someone has ever been a Registrant, and to request a copy of all or part of a Registrant's file. The communication policy was also updated to indicate that staff members can support the Director in responding to inquiries about Registrants or the policies and practices of the Registries. P103 is available in Appendix B, and can be downloaded from the USTUR's online policies and procedures manual: www.ustur.wsu.edu/policies-and-procedures/ustur-procedures/

External Collaboration

Shipment of data containing potentially identifiable information to collaborators works well when data is shared with a researcher who will do the data analysis independently. However, when USTUR faculty are working collaboratively to analyze data containing potentially identifiable information, a secure method of electronically sharing files among USTUR staff members and collaborators at different institutions is needed. In May 2021, the USTUR contacted WSU's information technology department to learn about secure options for sharing files containing potentially identifiable information with collaborators. Use of WSU's Office 365 OneDrive cloud service was recommended. This can be accomplished by creating a folder such as "External Collaborators" in the root of a USTUR staff member's OneDrive, and then creating sub-folders for each collaborating team so that files can be shared without co-mingling data. WSU allows this for personally identifiable information and protected health information data. Data can be shared with each collaborator by sharing a link to the subfolder for their project. This method will send each recipient a unique URL, and the recipient will be emailed a different one-time 10-digit password each time they open the file/folder. Alternately, USTUR staff members can sponsor a WSU "Friend ID" for a collaborator, if the individual will need to have access to other WSU services such as wireless and VPN access. A Friend ID is a WSU identity for an individual not otherwise affiliated with the University.

Other Modifications

A minor change was made to the instruction sheet for urine sampling, which will now ask the Registrants to document the start and end times instead of just the date. Additionally, Mark Gorelco was added to the IRB.

Registrant Statistics

Stacey L. McComish, *Associate in Research*

As of March 31, 2022, the Registries had 880 Registrants in all categories (Table 1). Of that number, 26 were living and 372 were deceased. The 26 living Registrants included five individuals who were registered for eventual whole-body donation, 17 for partial-body donation, and four for 'Special Studies,' i.e., a bioassay study with no permission for autopsy. There were also 482 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, 2022

Total living and deceased Registrants	398
Living Registrants	26
Potential partial-body donors	17
Potential whole-body donors	5
Special studies	4
Deceased Registrants	372
Partial-body donations	317
Whole-body donations	47
Special studies	8
Inactive Registrants	482
Total number of Registrants	880

Registrant Renewals

It was the USTUR's previous policy to offer all living Registrants an opportunity to renew their voluntary registrations every five years. However, 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. Three Registrants who had previously signed five-year agreements were sent one-time renewal paperwork shortly before their autopsy authorizations were set to expire. All three renewed their participation with the Registries, and their consent paperwork will remain valid unless terminated by action of the Registrant or the Registries.

Annual Newsletter

The USTUR distributes a newsletter to Registrants and their next-of-kin on an annual basis. The 2021 letter was mailed in December (Appendix C). It included a note from the USTUR's director, as well as information about recent USTUR publications and presentations, membership on scientific committees, the USTUR's plan to collect urine samples in 2022, the Health Physics Society (HPS) Ask the Experts Page, and an HPS interview of Dr. Avtandilashvili.

Registrant Deaths

During FY2022, the USTUR received three partial-body donations from individuals who had worked with actinides for decades. The first individual's most significant exposure was an inhalation of ^{239}Pu, which resulted in an estimated 12.7 nCi intake. The material type was most likely oxide. The second individual was involved in a number of skin and airborne contamination incidents; however, his primary intake was also an inhalation of plutonium oxide, which resulted in a systemic deposition of 4 nCi. The third individual was involved in numerous incidents involving wounds, skin contamination, and/or possible inhalation of plutonium; however, no detectable activities of actinides were found in his urine, or during in-vivo counting.

Registrant Status

The average age of living whole- and partial-body Registrants was 83.3±10.0 years and 83.2±13.3 years, respectively. The average age at death for the USTUR's deceased whole- and partial-body Registrants was 78.8±11.4 and 68.9±13.3 years, respectively.

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

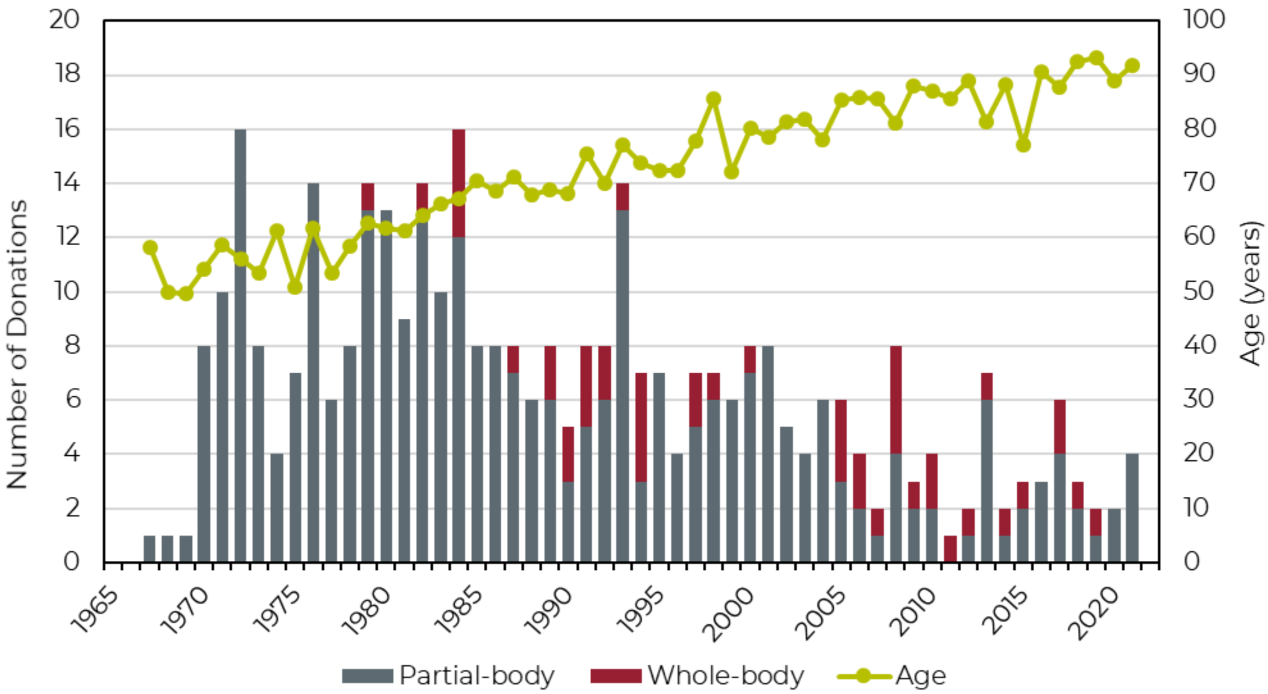


Fig. 2. Number of whole- and partial-body donations by calendar year and average age.

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.

FY2022 Data Entry

The USTUR currently retains documents containing health physics and bioassay records for 48 whole-body and 317 partial-body tissue donors, as well as 22 living potential donors and 12 special study cases (four living and eight deceased).

As of March 31, 2022, standardization of health physics records and bioassay data was completed for 22 living potential donors (five whole-body and 17 partial-body), and 288 deceased donors (47 whole-body and 241 partial-body). In total, 159,832 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 overall progress toward population of the health physics database since its inception in 2008.

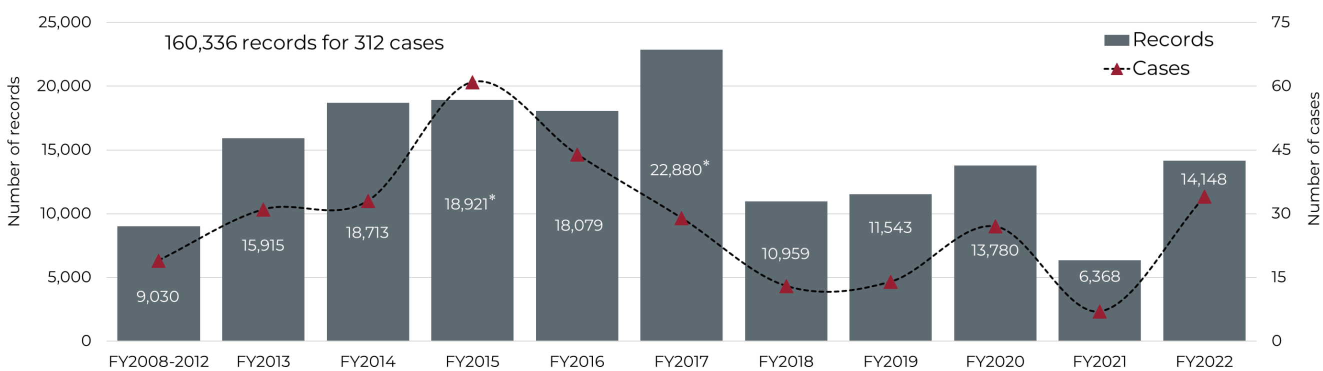


Fig. 3. FY2022 status of the USTUR health physics database. Includes two special study cases completed in FY2015 and FY2017 (*)

Five-year Database Progress

Significant progress in health physics database population has been made during FY2018 - FY2022 (Fig. 4). By the end of FY2017 (March 31, 2017), health physics records and bioassay data were standardized for 203 deceased donors (43 whole-body and 160 partial-body), 15 living potential donors (7 whole-body and 8 partial-body), and one special study case. This was 56% of the USTUR Registrant cases. As of March 31, 2022, population of the database was completed for 80% of all active USTUR Registrants. A total of 56,798 records was standardized during FY2017 – FY2022.

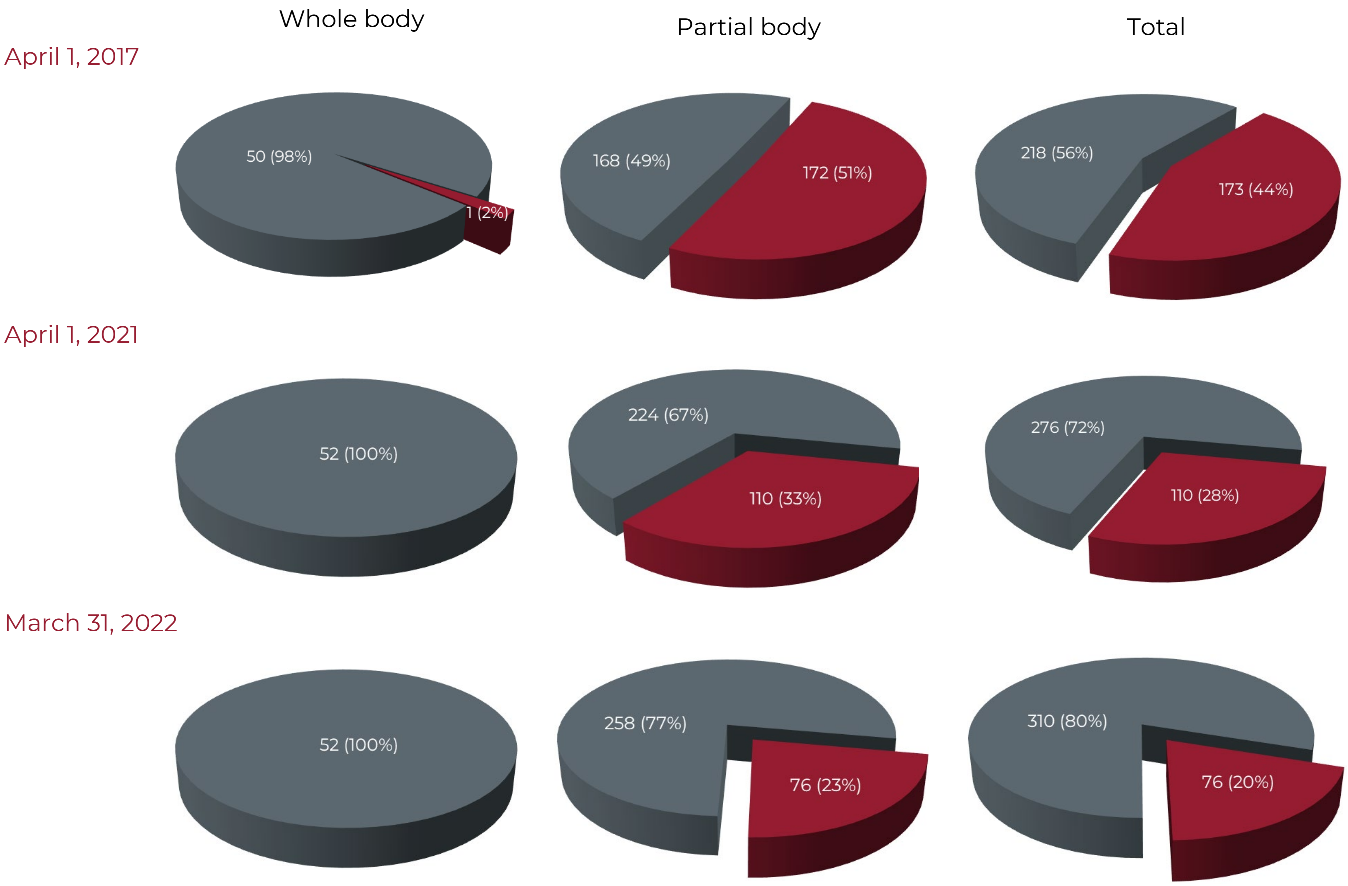


Fig. 4. FY2022 health physics database progress: ■ complete cases; ■ incomplete cases.

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).

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, and are deferred until we are able to hire appropriate student laboratory personnel to complete them.

THEMIS Inventory

As of March 31, 2022, 25,368 parent samples and 12,570 subsamples had been inventoried using the THEMIS database (Table 2).

Table 2. Inventoried samples as of March 31, 2022

Tissue type	Samples		
	Parent	Sub-	Total
USTUR donations			
Soft tissue samples	5,287	474	5,761
Bone samples	4,861	85	4,946
Histology slides	1,691	2,186	3,877
Acid solutions	6,936	1,184	8,120
Planchets	0	7,935	7,935
Paraffin blocks	0	48	162
ANL tissues & slides	1,414	434	1,848
LASL solutions	4,447	92	4,539
Blank and QC acids	442	60	502
Miscellaneous	290	72	362
Total	25,368	12,570	38,052

Long-term Trends

Figure 5 shows the cumulative number of inventoried samples at the end of each calendar year from 2010 to 2021. It can be seen that initial efforts focused on inventorying USTUR tissues and acids. From 2016 to 2019, laboratory personnel focused on LASL acids and USTUR planchets inventories. Since the beginning of the COVID-19 pandemic, only inventory activities associated with routine radiochemical operations have been performed. This is reflected in the gradual increase in the number of USTUR acids and planchets starting in 2020.

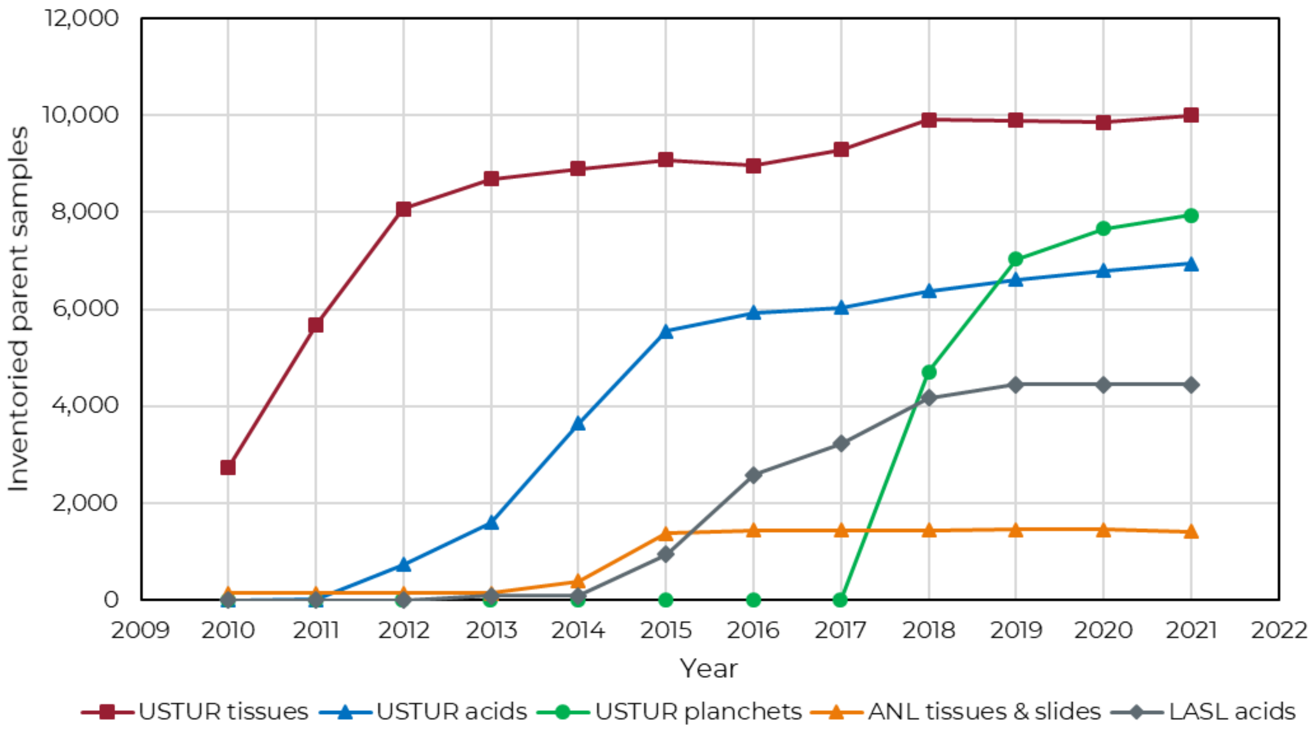


Fig. 5. Cumulative number of inventoried NHRTR samples at the end of each calendar year.

Radiochemistry Operations

George Tabatadze, *Research Assistant Professor*

This section describes specific activities and achievements of the Radiochemistry Group during FY2022.

Personnel

As of March 31, 2022, operation of the radiochemistry laboratory was supervised by Dr. Tolmachev (Principal Radiochemist) with two full-time personnel – Dr. George Tabatadze (Laboratory Manager) and Ms. Elizabeth Thomas (Radiochemist).

Facility and Equipment

Beginning FY2022, limited operational tasks were performed at the laboratory facility due to preparation of the worksite for new equipment installation. Three polypropylene fume hoods were delivered and installed at the USTUR radiochemistry laboratory in Q4 FY2022. The new fume hoods are expected to become operational in Q1 FY2023.

Radiochemistry laboratory fume hoods: old (top) and new (bottom).

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 FY2022, analyses of 99 tissue samples for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am, including 23 bone and 76 soft tissue samples from two partial-body donation, cases 0284 (died 2020) and 0417 (2019), were completed. Additionally, 195 tissue samples, including 67 bone and 128 soft tissue samples from six partial-body donations, were submitted for analysis. Figure 6 shows FY2017 – FY2022 tissue analysis progress.

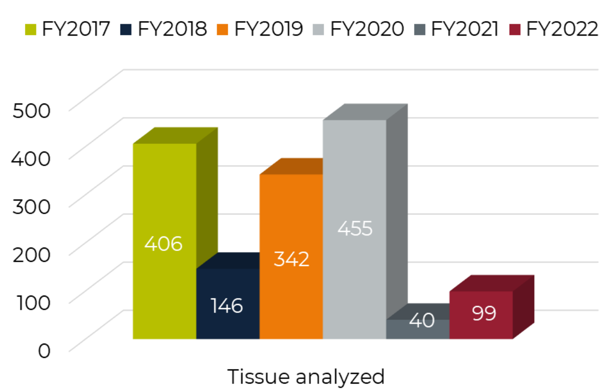


Fig. 6. USTUR tissue analysis progress in FY2017 – FY2022.

Radiochemistry Case Analysis

As of March 31, 2022, the USTUR had received 47 whole- and 317 partial-body donations, including three partial-body donations accepted during FY2022.

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

In FY2022, radiochemical analysis of one 'intact' partial-body donation (Case 0284) and one 'incomplete' partial-body donation (Case 0417) was complete. Radiochemistry status of these cases was changed to 'complete'. Radiochemical analysis of three previously 'intact' partial-body donations, cases 0452, 0475, and 0656, began in FY2022. Radiochemistry status of these cases was changed to 'incomplete'. Figure 7 shows FY2017 – FY2022 case analysis progress.

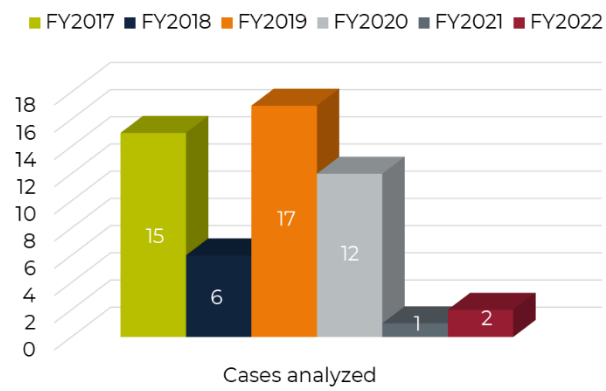


Fig. 7. USTUR case analysis progress in FY2017 – FY2022.

The status change of case analyses from FY2021 to FY2022 is shown in Figure 8.

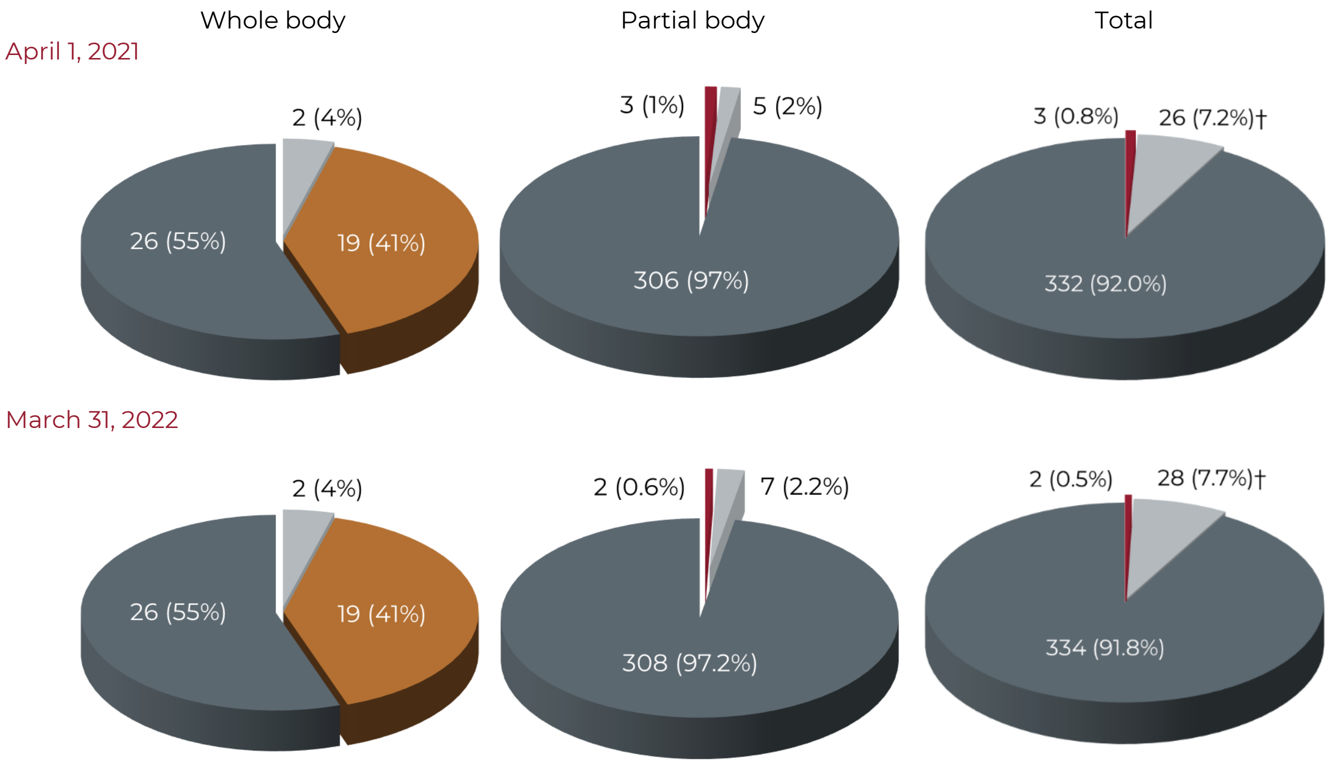


Fig. 8. Radiochemistry case analysis status: ■ Intact; ■ Incomplete; ■ Surveyed; ■ Complete.
† Includes 'Surveyed' whole-body cases.

Tissue Sample Backlog

The USTUR/NHRTR retains a tissue backlog of 2,080 samples from 28 whole- and partial-body cases. They remain 'Incomplete' as of March 31, 2022. This includes 1,781 tissue samples from 19 whole-body cases, and 299 tissues from nine partial-body cases. Of 2,080 backlog samples, 1,700 (82%) need to be analyzed for plutonium, 139 (7%) for americium, and 241 (11%) for uranium (Fig. 9).

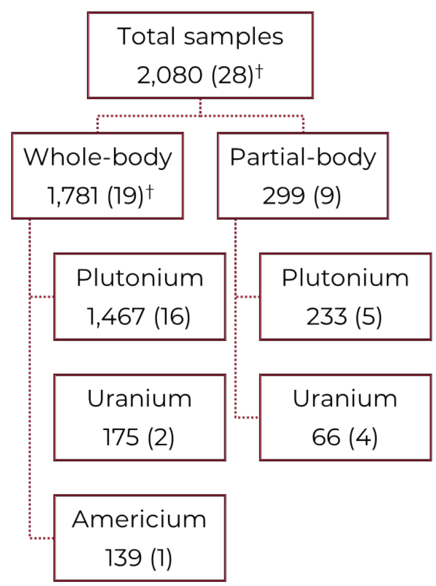


Fig. 9. USTUR tissue sample backlog at the end of FY2022. † Excludes two Thorotrast cases.

Database Harmonization

Stacey L. McComish, *Associate in Research*

A project is underway to harmonize the USTUR's database system, which includes seven databases that were purchased or developed in-house over the course of more than 25 years. Most of these databases started out as standalone databases; however, links were forged between them on an *ad hoc* basis. The resulting information structure involves both automated communication between databases and hand-copied movement of data.

To harmonize the database system, data entry is being automated and links between databases are being improved. This involves integrating the Inventory, Radiochemistry, Planchets, and Reagents databases such that they function as a single unit (Fig. 10).

Redesigning THEMIS

The existing THEMIS inventory database, which has been in use since 2008, must be redesigned to integrate with the Radiochemistry and other databases. Eight tasks associated with this project have been identified:

1. Design a new table structure for the inventory database
2. Build the new tables in SQL
3. Import data from THEMIS to the new inventory tables
4. Design a basic user interface for inventorying samples
5. Test this basic functionality
6. Develop advanced functionality
7. Test advanced functionality
8. Prepare documentation

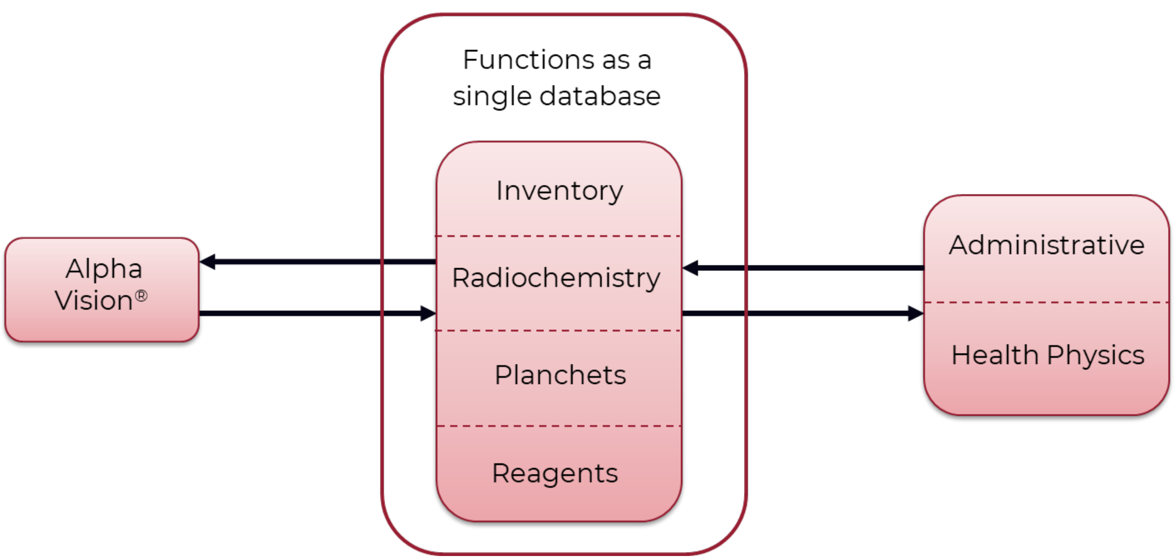


Fig. 10. Integrated USTUR database system.

Tasks 1-5 are associated with the process of rebuilding the inventory database such that that it can communicate with the Radiochemistry database. Tasks 6-7 will expand the inventory database to a laboratory information management system (LIMS).

Tasks 1 and 2 have been completed, though small changes continue to be made as the need arises. For example, two new tables were added, which will allow users to link images and other files to individual samples.

Tasks 3–5 are being worked on in parallel. Alex Tabatadze completed the import of data to tables that will be used for dropdown menus. This allowed other staff members to design and test 25 simple forms associated with creating lists for the dropdown menus. Meanwhile, Mr. Tabatadze continued to import data into some of the more complex tables. These tables present greater challenges, because they require data to be pulled from multiple THEMIS tables into a single new table. Additionally, some information needs to be parsed out of notes fields into single dedicated fields in the new database.

Tasks 6-8 are future work. Anticipated advanced functionality includes the ability to track changes in a sample's mass as the sample goes through the various steps of the radiochemistry process. This would allow staff to track a sample's mass as it changes from a wet tissue to a dried sample, ashed sample, and ultimately to an acid solution. Indeed, the groundwork has already been laid for this future work, in the form of tables that will be used to track these masses.

Standardizing Tissue Descriptions

A new system of standardized tissue descriptions was designed during FY2021. As a continuation of this effort, data from the old THEMIS tables was prepared for import into the new database. The initial goal was to check that dropdown menu lists were up to date; however, a big piece of this task ended up being quality assurance. A table of all THEMIS samples was generated, and each record was checked for ambiguous tissue names or incorrectly entered samples. Samples with unexpected data associated with them were checked for accuracy and updated with more accurate information when necessary.

2021 Advisory Committee Meeting Summary

Thomas L. Rucker, *Chair*

The Scientific Advisory Committee (SAC) for the USTUR held its annual meeting on April 8–9, 2021. Due to the COVID-19 pandemic, the meeting was held by videoconference.

Meeting Summary

The meeting included two half-day sessions that focused on the USTUR's research program and operation of the Registries (Appendix D).

The meeting opened with introductions by the USTUR director, Sergei Tolmachev, and opening remarks by the committee chair, Thomas Rucker. This was followed by an update on the Department of Energy (DOE)/EHSS-13 by DOE program manager, Joey Zhou. WSU Tri-Cities chancellor, Sandra Haynes, provided an update on the Tri-Cities campus, and WSU College of Pharmacy and Pharmaceutical Sciences (CPPS) dean, Mark Leid, summarized research at CPPS. The USTUR's faculty and staff gave several presentations on the operational aspects of the Registries, including financial developments, progress toward addressing recommendations from the 2020 SAC meeting, revision of a draft data quality objectives document, database harmonization, IRB changes, and our research and operational plan for FY2022. In addition, several technical presentations were given. Tulane University graduate student, Xirui Liu, discussed her work to quantify over- and under-classification of diseases on death certificates. Martin Šefl, a postdoctoral researcher at the USTUR, has been studying a group of Manhattan Project workers known as the UPPU "you-pee-Pu" follow-up group, and he presented his findings about biases in predicted post-mortem organ activities. Also, Joey Zhou presented his continuing effort on application of latent bone modeling approach for the estimation of plutonium concentration in the skeleton based on a limited bone sample analyses.

The second day was administrative in nature and was open only to SAC members, the USTUR staff, and the DOE program manager. The day began with a Q&A session, where the SAC and USTUR staff discussed their observations about topics presented during Day 1. This was followed by a "closed-door" executive session, where only SAC members remained in the meeting. After lunch the USTUR staff and the DOE program manager rejoined the meeting, and the SAC shared several comments regarding progress during the past year as well as recommendations for the coming year.

Specific Recommendations

1. We recognize the need for investments in capital equipment and infrastructure. We recommend funding for these be requested in the next 5-year submission and/or from donors.

2. We recommend that the 20-year-old Radiochemistry Quality Assurance Plan be updated.
3. We recommend that a USTUR overall Quality Assurance Plan be developed that includes software quality assurance and data backup practices.
4. We recommend that minimum detectable activities (MDA) and minimum quantifiable activities (MQA) be specified as measurement quality objectives (MQO) for sensitivity, accuracy, and precision at specific levels of activity. We recommend that the MDA be set at the 2 nCi or 5% of the Annual Limit of Intake (ALI). We recommend that the MQA be set at 10 times the MDA. Also, consider using batch blank results for calculation of total random uncertainties.
5. We continue to recommend improvements in the number of publications in the area of Radiochemistry. These may include the work with developing data quality objectives (DQO) and MQOs.
6. We continue to recommend increased participation of undergraduate and graduate students and postdoctoral fellows in USTUR research projects to enhance mutually beneficial activities with WSU.
7. We again recommend tracking progress towards benchmarks established in the 5- and 10-year plans and updating the plans annually.

Additional comments and observations are available at https://ustur.wsu.edu/sac/sac-meetings/sac-meeting-2021-recommendations/

SAC membership

Luiz Bertelli completed his first term as a health physics representative and was renewed for another three-year term.

Meeting Attendees

Five out of six SAC members participated in the meeting along with two DOE representatives, three WSU representatives, ten members of the USTUR, and 13 invited participants.

SAC members

- Thomas Rucker, Chair, Radiochemistry, *Leidos*
- Janet Benson, Toxicology, *Lovelace Biomedical Research Institute*
- Luiz Bertelli, Health Physics, *Los Alamos National Laboratory*
- Heather Hoffman, Epidemiology and Biostatistics, *George Washington University*
- Arthur “Bill” Stange, Occupational Health, *Oak Ridge Associated Universities (retired)*
- Timothy Ledbetter, Ethics, *Chaplaincy Health Care (unable to attend)*

DOE representatives

- Anthony Pierpoint, *Office of Domestic and International Health Studies (EHSS-13), Acting Director*
- Joey Zhou, *Program Manager (EHSS-13)*

Washington State University

- Sandra Haynes, *WSU Tri-Cities Chancellor*

- Mark Leid, *WSU College of Pharmacy and Pharmaceutical Sciences, Dean*
- Kathryn Meier, *WSU College of Pharmacy and Pharmaceutical Sciences, Associate Dean for Faculty and Student Development*

USTUR staff

- Sergei Tolmachev, *USTUR Director*
- Maia Avtandilashvili, *Assistant Research Professor*
- Margo Bedell, *Fiscal Specialist I*
- Florencio Martinez, *Medical Technologist*
- Stacey McComish, *Associate in Research*
- Martin Šefl, *Postdoctoral Research Associate*
- George Tabatadze, *Assistant Research Professor*
- Elizabeth Thomas, *Laboratory Technician II*
- Anthony Riddell, *Adjunct Faculty/Public Health England, UK*
- Daniel Strom, *Adjunct Faculty*

Invited guests

- Bastian Breustedt, *Karlsruhe Institute of Technology, Germany*
- John Brockman, *University of Missouri Research Reactor*
- John Boice, *NCRP/Vanderbilt University*
- Darrel Fisher, *Versant Medical Physics and Radiation Safety*
- Ashley Golden, *Oak Ridge Institute for Science and Education*
- John Klumpp, *Los Alamos National Laboratory*
- Ole Lind, *Norwegian University of Life Sciences, Norway*
- Xirui Liu, *Tulane University*
- Christopher Loffredo, *Georgetown University*
- Roger McClellan, *Independent Advisor, Toxicology and Risk Analysis*
- Bruce Napier, *Pacific Northwest National Laboratory*
- Deepesh Poudel, *Los Alamos National Laboratory*
- Sergey Romanov, *Southern Urals Biophysics Institute, Russia.*

The following sections highlight several research studies conducted at the USTUR in FY2022.

Latent Bone Modeling: Plutonium in Skeleton

Martin Šefl, *Postdoctoral Research Associate*

The skeleton is a major depository site for plutonium in the human body. The estimation of the total plutonium activity in the skeleton is a challenging problem. For most tissue donors at the Registries, a limited number of bone samples is available. The total skeleton activity is calculated using plutonium activity concentration (C_{skel}) and skeleton weight. If a limited number of bone samples is analyzed, C_{skel} could be estimated using multiple linear regression (MLR) of data from whole-body donors, where C_{skel} were estimated based on the analysis of a half of the skeleton. The caveat of MLR is that individual bone sample concentrations are correlated. Multicollinearity can be addressed by principal component regression (PCR). PCR was recently introduced to the analysis of the USTUR data to evaluate accuracy and precision of C_{skel} estimation. In this study, a principal component is called a latent bone, and PCR is the mathematical implementation of latent bone modelling (LBM). For 36 cases with 2–9 bone samples analyzed, C_{skel} was estimated as an arithmetic mean of measured concentrations and using LBM. LBM was based on PCR of data from 13 non-osteoporotic whole-body donors with C_{skel} range of 1.9–40.2 Bq kg^{-1}.

Figure 11 shows the best predictions using principal component regression with the first latent bone variable plotted against an arithmetic mean and their standard errors.

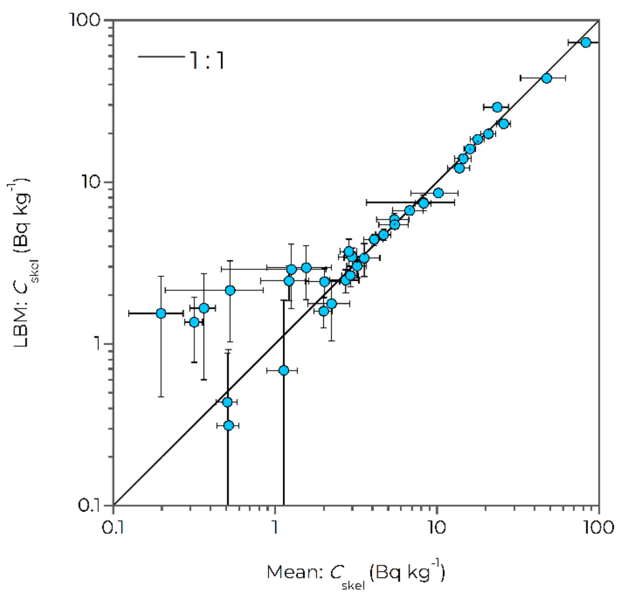


Fig. 11. Comparison of C_{skel} predictions: arithmetic mean *vs* LBM using first latent bone variable.

For plutonium concentrations >3 Bq kg^{-1}, C_{skel} values are close to 1:1-line (geometric mean of Mean/LBM = 1.01, n = 21) and LBM estimates have lower standard errors. A significant deviation from 1:1-line (GM of Mean/LBM=0.63, n = 15) and larger standard errors of LBM estimates were observed at C_{skel} <3 Bq kg^{-1}.

Manuscript: Šefl M, Avtandilashvili M, Zhou JY, Tolmachev SY. *Latent Bone Modelling for Estimation of Plutonium Concentration in Skeleton of Former Nuclear Workers* was submitted to Radiation Protection Dosimetry.

EPR Dosimetry

Alexander A Romanyukha, *Scientist, Naval Dosimetry Center*

Electron Paramagnetic Resonance (EPR) dosimetry in tooth enamel was applied to estimate doses of external irradiation received by early nuclear workers that were victims of various radiological accidents[1,2]. EPR has been proven to be a reliable method of retrospective dosimetry.

Eighteen molars and premolars were collected from ten USTUR Registrants. For seven individuals who worked with plutonium, life-time effective equivalent doses from penetrating external exposure ranged from 25 mSv to 375 mSv with the exposure period ranging from 8.0 years to 41.4 years. Of the remaining three individuals, two worked with uranium and one was medically exposed to thorium with no records of external exposure. Powderized samples of tooth enamel were prepared using a standard technique and measured by EPR. In order to obtain radiation dose, peak-to-peak amplitude of radiation-induced signal was related to calibration curve. Figure 12 shows an example of spectra of irradiated and unirradiated samples and a residual radiation-induced spectrum obtained as results of the spectral subtraction. A peak-to-peak amplitude was used as a measure of EPR radiation response. Radiation doses in enamel obtained by EPR will be compared with worksite-recorded doses available at the USTUR. Manuscript summarizing results of this study is in preparation[3].

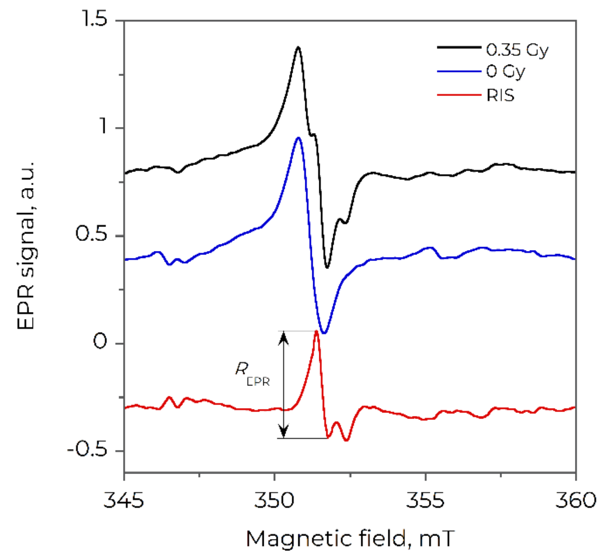


Fig. 12. EPR spectra of a tooth enamel sample irradiated at 0.35 Gy (top), unirradiated (middle), and resulted radiation-induced signal (bottom).

References

1. International Commission on Radiological Units and Measurements. ICRU Report 68, Retrospective assessment of exposure to ionising radiation. 2002.
2. Romanyukha AA, Ignatiev EA, Vasilenko EK, Drozhko EG, Wieser A, Jacob P, Keirim-Markus IB, Kleschenko ED, Nakamura N, Miyazawa C. EPR dose reconstruction for Russian nuclear workers. Health Physics 78(1): 15–20; 2000.
3. Romanyukha A, Tolmachev SY. Electron paramagnetic resonance dose measure-ments in teeth of tissue donors to the United States Transuranium and Uranium Registries.

For submission to Radiation Protection Dosimetry; 2022.

Disclaimer

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U. S. Government. Alexander Romanyukha is an employee of the U.S. Government. This work was prepared as part of his official duties. Title 17, U.S.C., x105 provides that copyright protection under this title is not available for any work of the U.S. Government. Title 17, U.S.C., x101 defines a U.S. Government work as a work prepared by a military Service member or employee of the U.S. Government as part of that person's official duties.

Radium in Human Brain

Dana L Arbova, *PhD Candidate, University of Missouri – Columbia*
John D Brockman, *Associate Professor, University of Missouri – Columbia*

Tissue samples from a radium worker available at the NHRTR were used for development of inductively coupled plasma mass spectrometry (ICP-MS) methods to measure ^{226}Ra ($T_{1/2}$ = 1,600 y) in human brain tissues.

This individual worked as a radium dial painter in the 1920s for almost 7 years. In 1973, a total body content of ^{226}Ra was measured as 1.077 µg (40 kBq). Using ICRP 20 whole-body retention function[1], an initial systemic deposition of ^{226}Ra for this individual was estimated to be 261.7 µg (9.7 MBq), resulting in ^{226}Ra skeletal dose of 50.5 Gy[2]. She died 6 decades after exposure at the age of 86.

For this study, the brain from this individual was dissected into five regions: cerebrum white matter, cerebrum gray matter, corpus callosum, cerebellum, and brainstem.

Two analytical protocols were developed for ^{226}Ra measurements in digested brain samples using: (i) direct quadrupole ICP-MS and (ii) multi-collector ICP-MS followed by cation-exchange chromatography. The instrumental limits of detection were 0.1 ng kg^{-1} (3.7 Bq kg^{-1}) and 0.5 pg kg^{-1} (19 mBq kg^{-1}), respectively.

The measured concentrations of ^{226}Ra in different brain regions ranged from 0.09–0.72 ng kg^{-1} (3.3–27 Bq kg^{-1}) and radium was non-uniformly distributed in the brain (Fig. 13).

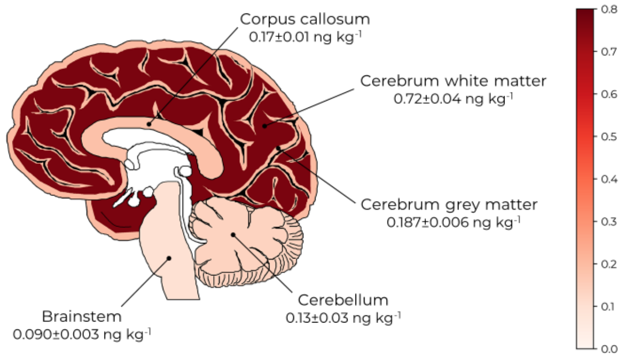


Fig. 13. ^{226}Ra distribution in human brain.

Manuscript summarizing results of this study was submitted for publication[3].

References

1. International Commission on Radiological Protection. Alkaline earth metabolism in adult man. ICRP Publication 20. Pergamon Press, Oxford; 1973.
2. Rowland RE. Radium in humans: A review of U.S. studies. United States; 1995.
3. Arbova DL, Tolmachev SY, Brockman JD. Quadrupole and multi-collector ICP-MS analysis of ^{226}Ra in brain from a radium dial painter. Submitted to Journal of Analytical Atomic Spectrometry; 2022.

Professional Activities and Services

During FY2022, the USTUR staff was actively involved in professional and academic activities nationally and internationally.

Professional Services

NCRP Council

Dr. Tolmachev continued to serve as a Council Member of the National Council on Radiation Protection and Measurements (NCRP) Program Area Committee 6 on Radiation Measurements and Dosimetry.

https://ncrponline.org/about/members/council-members/

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 (2017–2022).

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

NCRP Scientific Committee 6-12

Dr. Tolmachev and Dr. Avtandilashvili continued 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 (2018–2022).

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

NCRP Scientific Committee 6-13

Dr. Avtandilashvili was appointed to serve on the NCRP scientific committee (SC 6-13) on Methods and Models for Estimating Organ Doses from Intakes of Radium (2021–2023).

https://ncrponline.org/program-areas/sc-6-13-methods-and-models-for-estimating-organ-doses-from-intakes-of-radium/

U.S. DOE Russian Health Studies

Dr. Tolmachev continued to serve as an ad-hoc member of the Scientific Review Group of the U.S. DOE Russian Health Studies Program. He is a reviewer for Project 2.8 "Mayak Worker Tissue Repository".

https://www.energy.gov/ehss/russian-health-studies-program

Herbert M. Parker Foundation

Dr. Tolmachev and Dr. Tabatadze continued to serve as members of the Board of Trustees of the Herbert M. Parker Foundation (2016– present and 2019– present, respectively).

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

Hanford Advisory Board

Dr. Daniel J. Strom, a USTUR/CPPS adjunct faculty member, continued to serve as an alternate member of the Hanford Advisory Board (HAB) in a position representing the Benton-Franklin Public Health District. He also serves on the HAB's Public Involvement and Communication and Health Safety and Environment Protection committees.

"*The Hanford Advisory Board is a non-partisan and broadly representative body consisting of a balanced mix of the diverse interests that are affected by Hanford cleanup issues. As set forth in its charter, the primary mission of the Board is to provide informed recommendations and advice to the U.S. Department of Energy (DOE),* *the U.S Environmental Protection Agency (EPA), and the Washington Department of Ecology (Ecology) on selected major policy issues related to the cleanup of the Hanford site."*

https://www.hanford.gov/page.cfm/hab/

Health Physics Society International Collaboration Committee

Dr. George Tabatadze continued to serve as a member (2016–2022) of the International Collaboration Committee of the Health Physics Society.

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

Columbia Chapter of Health Physics Society

Dr. Martin Šefl was elected to serve as a secretary of the Columbia Chapter of Health Physics Society (CCHPS). Dr. Tabatadze continued to serve as the *ex-officio* president of the CCHPS (2018–2021).

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

WSU Radiation Safety Committee

Dr. Tabatadze continued to serve as a member (2019–2022) of the WSU Radiation Safety Committee (RSC). The RSC establishes and ensures compliance with radiation protection policies, reviews applications for, and approves the use of, radioactive materials and radiation-producing machines, and audits Radiation Safety Office records.

https://rso.wsu.edu/radiation-safety-committee/

Kyushu Environmental Evaluation Association

Dr. Tolmachev was re-appointed as a Technical Advisor (2020–2022) at the Kyushu Environmental Evaluation Association (Fukuoka, Japan). http://www.keea.or.jp/

Scientific Meetings

USTUR faculty attended and participated in the following scientific meetings:

- Virtual meetings on the Million Person Study Dosimetry, April 12, and August 3, 2021
- Virtual sessions of the NCRP Annual Meeting "Radiation and Flight: A Down-to-Earth Look at Risks", April 19 – 20, 2021
- Webinars of the Radiation Research Society (RRS), April 26 and 29, July 15 and 29, November 19, 2021, and March 11, 2022
- Webinars of the International Society of Radiation Epidemiology and Dosimetry (ISoRED), April 29, May 10, June 15, July 6, September 24, October 25, November 18, and December 1, 2021; January 15, and February 17, 2022
- Monthly virtual meetings of Radium Dial Painter Dosimetry Group, April 30, May 28, June 21, and August 2, 2021
- Virtual technical meetings of the North-West Regional HPS Chapter, May 20, June 18, September 1, October 5, and November 11, 2021
- Virtual sessions of the HPS First Annual Workshop – A Fresh Perspective, Clemson University, SC, May 23–26, 2021
- Virtual and in-person sessions of the 66th Health Physics Society Annual Meeting, Phoenix, AZ, July 25 – 29, 2021
- ICRP digital workshop "The Future of Radiological Protection", October 19 – 20, 2021
- Virtual 11th Workshop of the Million Person Study, October 28–29, 2021

- Virtual meeting of EURADOS WG7 Task Group on Internal Dosimetry for Emergency, November 10, 2021
- Virtual plenary meeting of EURADOS Working Group 7 (WG7), December 16, 2021
- Webinar of European Radiation Dosimetry Group (EURADOS), January 20, 2022
- Virtual public meeting of the National Academies of Science, Engineering and Medicine "Developing a long-term strategy for low-dose radiation research in the United States", January 24–25, 2022
- Virtual meeting of EURADOS Working Group 7 and WHO RAMPEN on Wound Contamination Project, March 2, 2022
- Webinar of the HPS Cascades Chapter "Radioactive source breach at the Harborview Medical Center in Seattle", March 10, 2022
- ICRP webinar on Relative Biological Effectiveness (RBE), March 16, 2022
- Virtual technical meeting of the HPS Baltimore-Washington Chapter "Revisiting the doses to Radium Dial Painters in the United States", March 24, 2022
- Virtual sessions of the NCRP Annual Meeting "Opportunities in radiation science: From low dose to climate change" March 28–29, 2022

Japanese Journal of Health Physics

Dr. Sergei Tolmachev continued to serve as a member (2011–2021) of the Editorial Board for the *Japanese Journal of Health Physics* (JJHP).

Austin Biometrics and Biostatistics

Dr. Maia Avtandilashvili continued to serve as a member (2016–2022) of the Editorial Board for the journal of *Austin Biometrics and Biostatistics*.

Professional Affiliations

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

- Radiation Research Society (USA)
- Health Physics Society (USA)
- 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 2021 to March 2022.

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 E of this report.

Published

USTUR-0554-20

Šefl M, Avtandilashvili M, Tolmachev SY. Inhalation of soluble plutonium: 53-year follow up of Manhattan project worker. Health Physics 120: 661-670; 2021.

USTUR-0557-20

Poudel D, Avtandilashvili M, Bertelli L, Klumpp J, Tolmachev SY. Modelling of long-term retention of high-fired plutonium oxide in the human respiratory tract: importance of scar-tissue compartments. Journal of Radiological Protection 41(4): 940-961; 2021.

USTUR-0571-20

Boice JD, Quinn B, Ansari A, Blake PK, Blattnig SR, Caffrey EA, Cohen SS, Golden AP, Held KD, Jokisch DW, Mumma M, Samuels C, Till JE, Tolmachev SY, Yoder RC, Zhou JY, Dauer LT. A million persons, a million dreams: A vision for a national center of radiation epidemiology and biology. International Journal of Radiation Biology 98(4): 795–821; 2022.

USTUR-0572-21

Avtandilashvili M, Tolmachev SY. Four-decade follow up of plutonium contaminated puncture wound treated with Ca-DTPA. Journal of Radiological Protection 41(4): 1122-1144; 2021.

USTUR-0573-21

Šefl M, Zhou JY, Avtandilashvili M, Tolmachev SY. Plutonium in Manhattan Project workers: using autopsy data to evaluate organ content and dose estimates based on urine bioassay for radiation epidemiology. PLOS One 16(10): e0259057; 2021 (*Open access*)

USTUR-0574-21

Martinez NE, Jokisch DW, Dauer LT, Eckerman KF, Goans RE, Brockman JD, Tolmachev SY, Avtandilashvili M, Mumma MT, Boice J, Jr, Leggett RW. Radium Dial Workers: Back to the Future. International Journal of Radiation Biology 98(4): 750–768; 2022.

USTUR-0575-21

Poudel D, Avtandilashvili M, Bertelli L, Klumpp J, Tolmachev SY. Modelling the long-term retention of plutonium in the human respiratory tract using scar-tissue compartments. Radiation Protection Dosimetry 196(3-4): 167-183; 2021.

USTUR-0578-21

Leggett RW, Tolmachev SY, Avtandilashvili M, Eckerman KF, Sgouros G, Woloschak GE. NCRP Commentary 31: Development of kinetic and anatomical models for brain dosimetry for internally deposited radionuclides. Bethesda,

MD, USA: National Council on Radiation Protection and Measurements, 2022.

USTUR-0592-21

Strom DJ, Tabatadze G. Why "measurand" is the first scientific word we should teach health physicists. Health Physics 122(5): 607–613 2022.

USTUR-0569-20A

Šefl M, Zhou JY, Avtandilashvili M, S. L. McComish, D. J. Strom, Tolmachev SY. Uncertainty analysis on organ activities and intakes from occupational exposure to plutonium. Health Physics 122 (4 Suppl 1): 10; 2022.

USTUR-0576-21A

Šefl M, Avtandilashvili M, Tolmachev SY. USTUR Whole-body Case 0680: 53-year follow-up of a Manhattan Project worker. Health Physics 122 (4 Suppl 1): 60; 2022.

USTUR-0577-21A

Tabatadze G, Avtandilashvili M, Tolmachev SY. Comparison of two methods to estimate skeletal plutonium concentration from limited sets of bones. Health Physics 122 (4 Suppl 1): 64; 2022.

USTUR-0579-21A

Poudel D, Avtandilashvili M, Bertelli L, Klumpp J, Tolmachev SY. Analysis of long-term retention of plutonium in the respiratory tract of four workers: Health Physics 122 (4 Suppl 1): 55; 2022.

USTUR-0580-21A

Zhou JY, Avtandilashvili M, Tolmachev SY. Latent Bone modeling approach to estimate plutonium activity concentration in human skeleton. Health Physics 122 (4 Suppl 1): 71–72; 2022.

USTUR-0581-21A

Tolmachev SY, Avtandilashvili M, Zhou JY. Effect of osteoporosis on latent bone models to estimate plutonium activity concentration in human skeleton. Health Physics 122 (4 Suppl 1): 66; 2022.

USTUR-0582-21A

Zhou JY, Avtandilashvili M, Tolmachev SY. Uncertainty evaluation of skeleton plutonium activity concentration estimated from a latent bone model. Health Physics 122 (4 Suppl 1): 72; 2022.

USTUR-0583-21A

Martinez NE, Jokisch DW, Leggett RW, Eckerman KF, Tolmachev SY, Mumma MT, Dauer LT, Boice JD. Radium Dial Painters: An overview. Health Physics 122 (4 Suppl 1): 7–8; 2022.

USTUR-0584-21A

Jokisch DW, N. E. Martinez, Leggett RW, Eckerman K, Dauer LT, Tolmachev S, Mumma M, Boice JD. Dosimetry for a Radium Dial Painter Cohort - Past Approaches and Improvements. Health Physics 122 (4 Suppl 1): 6–7; 2022.

USTUR-0585-21A

Tolmachev SY, Avtandilashvili M, Zhou JY. Latent bone modeling approach to select best combination of bones for estimating plutonium activity concentration in human skeleton. Health Physics 122 (4 Suppl 1): 66–67; 2022.

USTUR-0587-21

Tolmachev SY, McComish SL, Avtandilashvili M. United States Transuranium and Uranium Registries Annual Report: April 1, 2020 – March 31,

2021. United States Transuranium and Uranium Registries; USTUR-0587-21, Richland, WA, 2021.

Presented

Invited

USTUR-0609-22P

Avtandilashvili M. U. S. Transuranium and Uranium Registries: Plutonium contaminated wound cases. Podium presentation at the EURADOS/WHO-RAMPEN Virtual Meeting on Contaminated Wound Project, March 2, 2022.

Podium

USTUR-0569-20A

Šefl M, Zhou JY, Avtandilashvili M, McComish SL, Strom DJ, Tabatadze G, Tolmachev SY. Uncertainty analysis on organ activities and intakes from occupational exposure to plutonium. HPS First Annual Workshop - A Fresh Perspective, Clemson University, SC, May 23 – 26, 2021.

USTUR-0583-21A

Martinez NE, Jokisch DW, Leggett RW, Eckerman KF, Tolmachev SY, Mumma MT, Dauer LT, Boice JD. Radium Dial Painters: An overview. HPS First Annual Workshop - A Fresh Perspective, Clemson University, SC, May 23 – 26, 2021.

USTUR-0584-21A

Jokisch DW, Martinez NE, Leggett RW, Eckerman KF, Dauer LT, Tolmachev SY, Mumma MT, Boice JD. Dosimetry for a Radium Dial Painter cohort - Past approaches and improvements. HPS First Annual Workshop - A Fresh Perspective, Clemson University, SC, May 23 – 26, 2021.

USTUR-0576-21A

Šefl M, Avtandilashvili M, Tolmachev SY. USTUR Whole-body Case 0680: 53-year follow-up of a Manhattan Project worker. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0577-21A

Tabatadze G, Avtandilashvili M, Tolmachev SY. Comparison of two methods to estimate skeletal plutonium concentration from limited sets of bones. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0579-21A

Poudel D, Avtandilashvili M, Bertelli L, Klumpp J, Tolmachev SY. Analysis of long-term retention of plutonium in the respiratory tract of four workers: Bound fraction vs. scar-tissue compartments. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0580-21A

Zhou JY, Avtandilashvili M, Tolmachev SY. Latent Bone modeling approach to estimate plutonium activity concentration in human skeleton. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0581-21A

Tolmachev SY, Avtandilashvili M, Zhou JY. Effect of osteoporosis on latent bone models to estimate plutonium activity concentration in human skeleton. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0582-21A

Zhou JY, Avtandilashvili M, Tolmachev SY. Uncertainty evaluation of skeleton plutonium activity concentration estimated from a latent bone model. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0585-21A

Tolmachev SY, Avtandilashvili M, Zhou JY. Latent bone modeling approach to select best combination of bones for estimating plutonium activity concentration in human skeleton. 66th Health Physics Society Meeting, Phoenix, AZ, July 25–29, 2021.

USTUR-0591-21A

Šefl M, Avtandilashvili M, Tolmachev SY. Fifty-three-year follow-up of a Manhattan Project worker. WSU College of Pharmacy and Pharmaceutical Sciences Research Day, Spokane, WA, August 13, 2021.

USTUR-0594-21A

Šefl M, Avtandilashvili M, Tolmachev SY. Caveats of plutonium internal dosimetry: from biokinetics to dose estimates. Dny Radiační Ochrany 2021 (Days of radiation protection 2021), Nuclear Physics Institute of Czech Academy of Sciences (online), November 8–12, 2021.

USTUR-0597-21A

Poudel D, Avtandilashvili M, Bertelli L, Klumpp J, Tolmachev SY. Regional retention of plutonium in the respiratory tract of four acutely-exposed workers can be described using scar-tissue compartments. 2022 IRPA North American Regional Congress, St. Louise, MO, February 20–23, 2022.

Poster

USTUR-0586-21A

Liu X, McComish SL, Martinez F, Zhou JY, Tolmachev SY. Evaluation of over- and under-classification of underlying cause of death on death certificate from a small all-autopsied population of former nuclear workers. 2021 American Public Health Association (APHA) Annual Meeting, Denver, CO, October 23–27, 2021.

Bibliographic Metrics

Stacey L. McComish, *Associate in Research*

Since its inception in 1968, the USTUR has published 287 papers in conference proceedings and peer-reviewed journals, 30 books/book sections, 116 abstracts in journals, and 26 editorial journal publications such as letters to the editor. These publications were authored by USTUR staff, SAC members, and/or emeritus/adjunct faculty.

Peer-reviewed papers by USTUR authors have appeared in 41 different journals, with a highest impact factor of 13.352 (Environment International). Four journals account for 73% of these papers: Health Physics (2.922), Radiation Protection Dosimetry (0.954), the Journal of Radioanalytical and Nuclear Chemistry (1.754), and Radiation Research (3.372).

The USTUR's publications profile was tracked online through the Publons bibliographic service. Publons generates citation metrics for journal articles in the Web of Science collection. In the past, the USTUR has used Publons to track all publication types. However, Publons is better suited to track citation metrics for journal articles, and the following information applies only to peer-reviewed journal articles. Publons has citation data for 238 USTUR publications. These articles were cited 4,258 times, and the USTUR has an *h*-index of 33. 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 the number of times articles were cited each year. To explore the USTUR's publications visit:

https://www.webofscience.com/wos/author/record/370358

Note: Since the end of FY2022, Publons has moved to the Web of Science, which requires that an account be set up to view a complete list of USTUR publications. The "free view" displays the ten most recent publications and provides citation metrics.

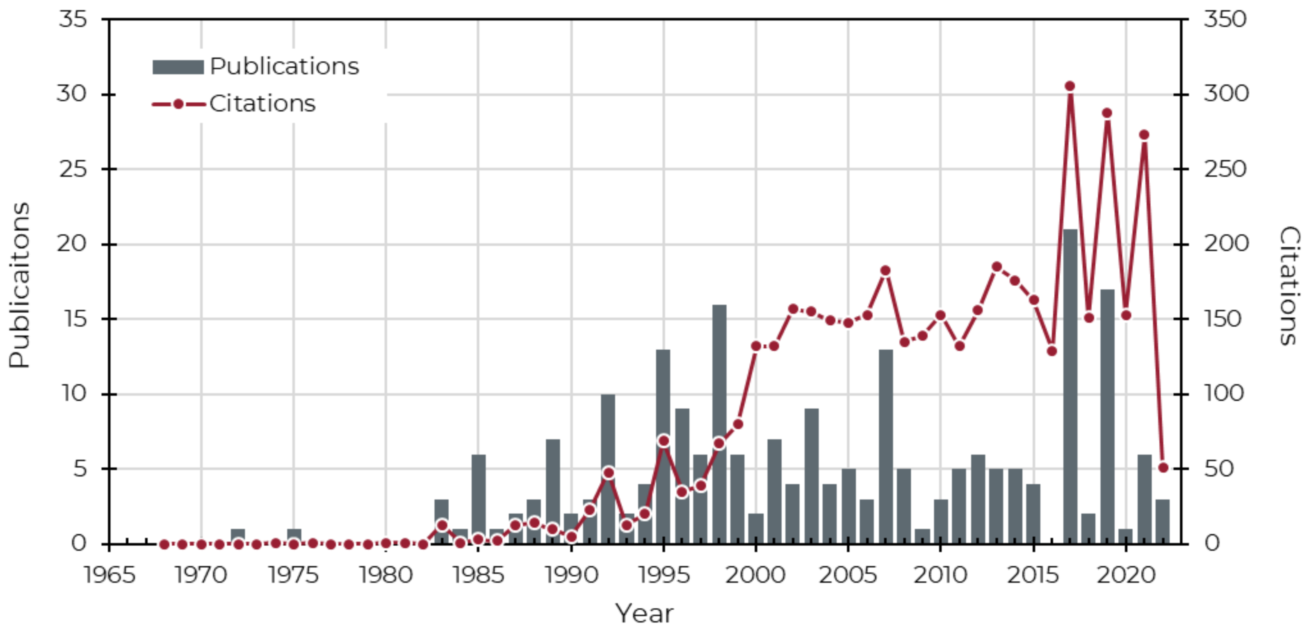
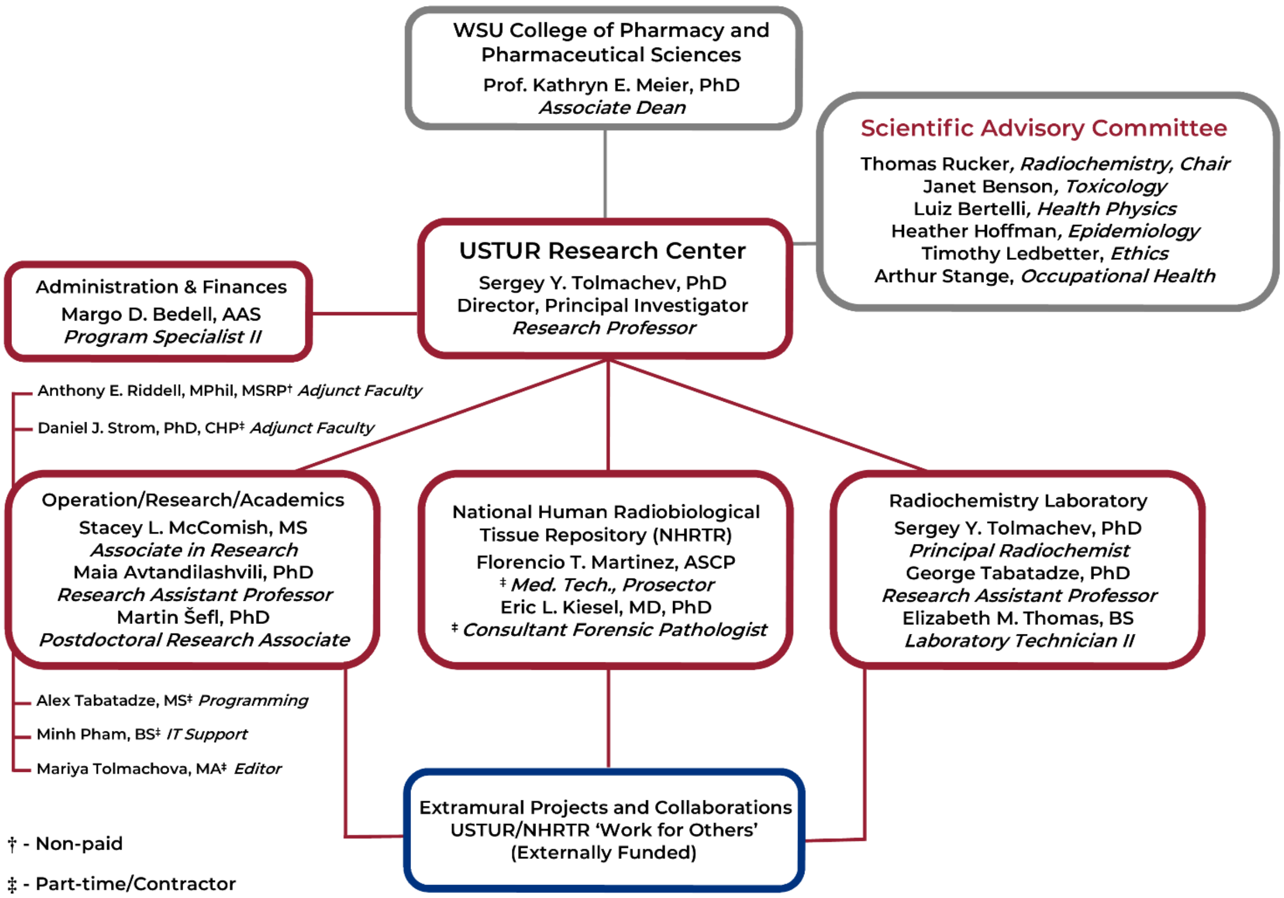


Fig 14. The number of USTUR journal publications per year, and the number of times articles were cited in each year.

Appendix A



USTUR Research Center organization structure during FY2022.

Appendix B

NEWSLETTER USTUR

ISSUE 27 | DECEMBER 2021
USTUR-0600-21

DIRECT FROM THE DIRECTOR

Dear Registrants and Families.

This is a time of the year when I have an opportunity to tell you about the USTUR's activities and achievements.

This year continued to be challenging due to coronavirus pandemic. However, after 18 months working from home and reduced laboratory operations, we returned to normal activities and operations in July. Upon return, we submitted the U.S. DOE grant to manage and operate the Registries for the next 5 years (April 1, 2022 – March 31, 2027) with a request for about a 10% funding increase. If approved, this will allow us to keep up with inflation and bring stability to the Registries in the coming years.

During 2021 alone, 7 papers were published in scientific journals and 13 presentations were given. Specifically, I would like to highlight two papers. Martin Šefl received an award from the Czech Society for Radiation Protection for the best work written by a young scientist in the field of radiation protection for the paper "Inhalation of Soluble Plutonium: 53-year Follow-up of Manhattan Project Worker". Additionally, our collaborative research with Los Alamos National Laboratory "Regional Retention of Plutonium in the Respiratory Tract of Four Acutely-exposed Workers can be Described using Scar-tissue Compartments" has been nominated by the Health Physics Society for the International Radiation Protection Association's 2022 North American Regional Congress Young Scientists and Professionals Award.

The USTUR's research continued to contribute to the National Council on Radiation Protection and Measurements (NCRP). Scientific data and knowledge generated by the Registries were used in NCRP Commentary 31 "Development of Kinetic and Anatomical Models for Brain Dosimetry for Internally Deposited Radionuclides". This year, the USTUR expended its scientific involvement in NCRP research activities. Maia Avtandilashvili was appointed as a member of newly established NCRP Scientific Committee "Methods and Models for Estimating Organ Doses from Intakes of Radium".

More details about Registries progress and discoveries are included elsewhere in this Newsletter. Our thanks go out to you and we wish you a happy holiday season!

~ Sergei Tolmachev ~

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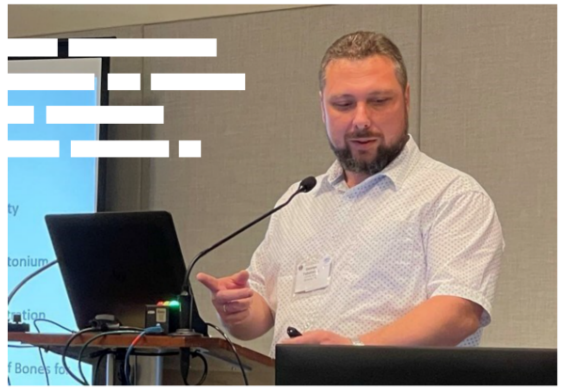
LEARNING FROM PLUTONIUM AND URANIUM WORKERS

During 2020, COVID restrictions meant that USTUR staff largely worked from home, and many scientific conferences were cancelled. Indeed, this slowed down certain operational aspects of the Registries, such as analyzing tissues for actinides. However, it also provided an unexpected opportunity to focus on research involving existing data. During 2021, seven papers were published in scientific journals, and seven more were being prepared for submission. Eight of the 14 total papers will have a USTUR faculty member as the lead author. Additionally, scientific conferences have resumed using virtual, in-person, or hybrid formats. This year, USTUR faculty have been authors on 13 presentations at five conferences.



George Tabatadze at the Health Physics Society's Annual Meeting

A BIG Thank You to our Registrants and their families!

Papers and presentations are just two of the ways that we are making sure that what we learn from Registrant donations continues to inform modern research and practices in radiation safety. USTUR faculty are also members of various committees where USTUR research can be applied in the local community, as well as at national and international levels.

SEVEN PAPERS PUBLISHED IN 2021

- Avtandilashvili and Tolmachev. Four-decade follow up of plutonium contaminated puncture wound treated with Ca-DTPA.
- Boice et al. A million persons, a million dreams: A vision for a national center of radiation epidemiology and biology.
- Martinez et al. Radium dial workers: Back to the future.
- Poudel et al. Long-term retention of plutonium in the respiratory tracts of two acutely-exposed workers: Estimation of bound fraction.
- Poudel et al. Modeling the long-term retention of plutonium in the human respiratory tract using scar-tissue compartments.
- Šefl et al. Inhalation of soluble plutonium: 53-year follow-up of Manhattan Project worker.
- Šefl et al. Plutonium in Manhattan Project workers: Using autopsy data to evaluate organ content and dose estimates based on urine bioassay with implications for radiation epidemiology.

13 PRESENTATIONS: 5 MEETINGS

- 7 Health Physics Society Annual Meeting
- 3 Health Physics Society Midyear Workshop
- 1 Annual American Public Health Association Meeting
- 1 Days of Radiation Protection (Czech Republic)
- 1 WSU College of Pharmacy and Pharmaceutical Sciences Research Day

COMMITTEE MEMBERSHIP: A FEW EXAMPLES

01 U.S. Department of Energy Russian Health Studies

Sergei Tolmachev is an ad-hoc member of the scientific review group for Project 2.8: Mayak Worker Tissue Repository. This repository holds tissues from workers who were employed at the former Soviet Union's first nuclear weapons production facility.

02 National Council on Radiation Protection and Measurements

Sergei Tolmachev and Maia Avtandilashvili contribute to several NCRP committees, which provide guidance on topics including: meeting the needs of the nation for radiation protection (ST), methods and models for estimating organ doses from intakes of radium (MA), and the development of models for brain dosimetry from internally incorporated radionuclides (ST, MA). The commentary on brain dosimetry will be published next year.

03 Herbert M. Parker Foundation

Sergei Tolmachev and George Tabatadze serve on the Board of Trustees for the Parker Foundation. The Parker Foundation enhances public understanding of science and technology through outreach, education, and semi-annual public lectures. Dr. Tabatadze will be the general chair starting April 2022.

04 Hanford Advisory Committee Board

Daniel Strom is a member of the Hanford Advisory Board, which provides "informed recommendations and advice to the U.S. Department of Energy (DOE), the U.S Environmental Protection Agency (EPA), and the Washington Department of Ecology (Ecology) on selected major policy issues related to the cleanup of the Hanford site." Source: https://www.hanford.gov/page.cfm/hab

3

P103 Communications

Created 05/92
Revised 02/21

Approved by Sergei Y. Tolmachev, Director
February 2021

This policy establishes the basic mechanism for response to queries regarding the U.S. Transuranium and Uranium Registries.

General practice is open communication

It is general policy of the Registries to openly and freely communicate scientific results and other information regarding their activities. Normally, this is accomplished through peer-reviewed scientific literature and Annual Reports of operations, which are also made available via the Internet at http://www.ustur.wsu.edu. Specific inquires will be answered fully provided that such response is in full accord with the legal and contractual requirements and does not violate the Registries policy with respect to the privacy of individual Registrants, and does not constitute an undue burden, significant intrusion, or delay of the program.

Response to specific inquiries

Inquiries regarding the Registrants or the policies and practices of the Registries should be addressed to the Director of the Registries, or other staff members.

Registries' publications provide response to inquiries

The operations and progress of the Registries are described in various publications, including an Annual Report published at the end of each calendar year. The Annual Report and a listing of open literature publications are also available via the USTUR's webpage. These publications provide the basic information regarding the Registries and are freely provided upon request. The Registries will maintain a list of correspondents to whom Annual Reports shall be routinely sent, and will provide, without cost, a copy of the current Annual Report, to anyone who requests it.

It is the policy of the Registries to promptly communicate all information on a specific Registrant to that individual, if living, or to the next-of-kin when the data become available. To request information from a Registrant file, living Registrants must complete form F103a *Data Request: Living Registrant*, and next-of-kin to deceased Registrants must complete F103b *Data Request: Deceased Registrant*. These forms must be returned to the USTUR, along with supporting documents to confirm identity and/or medical power of attorney.

Responses to inquiries maintain Registrants' privacy

To ensure the privacy of each individual Registrant, as required by Washington State law, the Federal Privacy Act, and ethical requirements, the Registries do not identify individual Registrants, unless required to do so by law or regulation, or specifically requested by the Registrant, or next-of-kin in the case of deceased Registrants. Registrants are identified in open literature by a unique four-digit number, and every attempt is made to avoid the publication of personal identifiers or data that would lead to the identification of the individual.

Appendix D

UNITED STATES TRANSURANIUM AND URANIUM REGISTRIES

College of Pharmacy and Pharmaceutical Sciences
Washington State University

2021 Scientific Advisory Committee Meeting

Zoom Teleconference (Pacific Daylight Time), April 8–9, 2021

Day 1

Thursday, April 8, 2021

07:30 – 08:00	Zoom in	All
08:00 – 08:10	Welcome & Introduction	S. Tolmachev, *USTUR Director*
08:10 – 08:15	Opening Remarks	T. Rucker, *SAC Chair*
08:15 – 08:20	Updates from DOE/AU-13	J. Zhou, *DOE Manager*
08:20 – 08:35	WSU Tri-Cities Updates	S. Haynes, *WSU TC Chancellor*
08:35 – 08:50	WSU/CPPS News	M. Leid, *CPPS Dean*
08:50 – 09:00	Administrative & Financial Developments	M. Bedell, *Program Specialist II*
09:00 – 09:40	2020 SAC Recommendations & Overview	S. Tolmachev, *USTUR Director*
09:40 – 09:50	*Coffee Break*	
09:50 – 10:05	Data Quality Objective Report	G. Tabatadze, *Assistant Professor*
10:05 – 10:20	Registrant Statistics and IRB	S. McComish, *Associate in Research*
10:20 – 10:35	Database Harmonization	S. McComish, *Associate in Research*
10:35 – 10:50	Autopsy *vs* Death Certificate Reports	X. Liu, *Graduate Student*
10:50 – 11:00	*Coffee Break*	
11:00 – 11:15	Uncertainty Project	M. Šefl, *Research Associate*
11:15 – 11:30	Latent Bone Project	J. Zhou, *Scientist*
11:30 – 12:00	Research & Operation: Plan for FY2022	S. Tolmachev, *USTUR Director*
12:00 – 12:30	Discussion and Q & A	USTUR, DOE, SAC, Guests

Day 2

Friday, April 9, 2020 – SAC, DOE and USTUR Management

08:30 – 08:40	SAC Membership	S. Tolmachev, *USTUR Director*
08:40 – 09:00	SAC Q & A	T. Rucker, *SAC Chair*
9:00 – 12:00	SAC Executive Session	T. Rucker, *SAC Chair*
12:00 – 13:00	*Lunch*	
13:00 – 14:00	SAC Debriefing	T. Rucker, *SAC Chair*

Appendix E

USTUR-0554-20

Inhalation of soluble plutonium: 53-year follow up of Manhattan project worker

M. Šefl, M. Avtandilashvili, S.Y. Tolmachev

U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA

This whole-body tissue donor to the United States Transuranium and Uranium Registries was occupationally exposed to plutonium nitrate-dioxide mixture via chronic inhalation. This individual was involved in the Manhattan Project operations, and later participated in medical follow-up studies. Soft tissues and bones collected at autopsy were analyzed for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am. Fifty-three years post intake, 700±2 Bq of $^{239+240}$Pu were still retained in the skeleton, 661±11 Bq in the liver, and 282±3 Bq in the respiratory tract. Bioassay measurements and organ activities at the time of death were used to estimate the intake and radiation doses using the TAURUS internal dosimetry software. For this individual, ICRP Publication 130 Human Respiratory Tract Model with case-specific particle size of 0.3 μm, ICRP Publication 100 Human Alimentary Tract Model, and ICRP Publication 141 Plutonium Systemic Model adequately described long-term plutonium retention and excretion. The total cumulative $^{239+240}$Pu intake of 31,572 Bq was estimated; of which, 24,708 Bq (78.3%) were contributed by inhalation of plutonium nitrate and 6,864 Bq (21.7%) of plutonium dioxide. The committed equivalent doses to the red bone marrow, bone surface, liver, lungs, and brain were 0.71 Sv, 6.5 Sv, 8.3 Sv, 3.7 Sv, and 0.067 Sv, respectively. The committed effective dose was 1.22 Sv.

Health Physics 120: 661-670; 2021.

USTUR-0557-20

Modelling of long-term retention of high-fired plutonium oxide in the human respiratory tract: importance of scar-tissue compartments

D. Poudel[1], M. Avtandilashvili[2], L. Bertelli[1], J. A. Klumpp[1], S. Y. Tolmachev[2]

[1] *Radiation Protection Division, Los Alamos National Laboratory, Los Alamos, NM*
[2] *U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA*

The U.S. Transuranium and Uranium Registries whole-body tissue donor Case 0407 had an acute intake of ‘high-fired’ plutonium oxide resulting from a glove-box fire in a fabrication plant at a nuclear defense facility. The respiratory tract of this individual was dissected into five regions (larynx, bronchi, bronchioles, alveolar-interstitial, and thoracic lymph nodes) and analyzed for plutonium content. The

activities in certain compartments of the respiratory tract were found to be higher than expected from the default models described in publications of the International Commission on Radiological Protection. Because of the extremely slow rate of dissolution of the material inhaled, the presence of bound fraction is incapable of explaining the higher-than-expected retention. A plausible hypothesis – encapsulation of plutonium in scar tissues – is supported by the review of literature. Therefore, scar-tissue compartments corresponding to the larynx, bronchi, bronchioles and alveolar-interstitial regions were added to the existing Human Respiratory Tract Model structure. The transfer rates between these compartments were determined using Markov Chain Monte Carlo analysis of data on urinary excretion, lung counts and post-mortem measurements of the liver, skeleton and regional retention in the respiratory tract. Modelling of the data showed that approximately 30% of plutonium activity in the lung was sequestered in scar tissues. The dose consequence of such sequestration is qualitatively compared against that of chemical binding.

Journal of Radiological Protection 41(4): 940-961; 2021.

USTUR-0572-21

Four-decade follow up of plutonium contaminated puncture wound treated with Ca-DTPA

M. Avtandilashvili, S. Y. Tolmachev

U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA

Contaminated wounds are a common route of internal deposition of radionuclides for nuclear and radiation workers. They may result in significant doses to radiosensitive organs and tissues in an exposed individual's body. The United States Transuranium and Uranium Registries' whole-body donor (Case 0303) accidentally punctured his finger on equipment contaminated with plutonium nitrate. The wound was surgically excised and medically treated with intravenous injections of Ca-DTPA. A total of 16 g Ca-DTPA was administered in 18 treatments during the 2 months following the accident. Ninety-three urine samples were collected and analysed over 14 years following the accident. An estimated ^{239}Pu activity of 73.7 Bq was excreted during Ca-DTPA treatment. Post-mortem radiochemical analysis of autopsy tissues indicated that 40 years post-accident 21.6 ± 0.2 Bq of ^{239}Pu was retained in the skeleton, 12.2 ± 0.3 Bq in the liver, and 3.7 ± 0.1 Bq in other soft tissues; 1.35 ± 0.02 Bq of ^{239}Pu was measured in tissue samples from the wound site. To estimate the plutonium intake, late urine measurements, which were unaffected by chelation, and post-mortem radiochemical analysis results were evaluated using the IMBA Professional Plus software. The application of the National Council on Radiation Protection and Measurements wound model with an assumption of intake material as a predominantly strongly retained soluble plutonium compound with a small insoluble fraction adequately described the data (p= 0.46). The effective intake was estimated to be 50.2 Bq of plutonium nitrate and 1.5 Bq of the fragment. The prompt medical intervention with contaminated tissue excision and subsequent Ca-DTPA decorporation therapy reduced ^{239}Pu activity available for uptake and long-term retention in this individual's systemic organs by a factor of 38.

Journal of Radiological Protection 41(4): 1122-1144; 2021.

USTUR-0573-21

Plutonium in Manhattan Project workers: using autopsy data to evaluate organ content and dose estimates based on urine bioassay for radiation epidemiology

M. Šefl [1], J. Y. Zhou[2], M. Avtandilashvili[1], S. Y. Tolmachev[1]

[1]*U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA*
[2]*U.S. Department of Energy, Washington, DC*

Purpose: Radiation dose estimates in epidemiology typically rely on intake predictions based on urine bioassay measurements. The purpose of this article is to compare the conventional dosimetric estimates for radiation epidemiology with the estimates based on additional post-mortem tissue radiochemical analysis results.

Methods: The comparison was performed on a unique group of 11 former Manhattan Project nuclear workers, who worked with plutonium in the 1940s, and voluntarily donated their bodies to the United States Transuranium and Uranium Registries.

Results: Post-mortem organ activities were predicted using different sets of urine data and compared to measured activities. Use of urinalysis data collected during the exposure periods overestimated the systemic (liver+skeleton) deposition of 239Pu by 155±134%, while the average bias from using post-exposure urinalyses was -4±50%. Committed effective doses estimated using early urine data differed from the best estimate by, on average, 196±193%; inclusion of follow-up urine measurements in analyses decreased the mean bias to 0.6±36.3%. Cumulative absorbed doses for the liver, red marrow, bone surface, and brain were calculated for the actual commitment period.

Conclusion: On average, post-exposure urine bioassay results were in good agreement with post-mortem tissue analyses and were more reliable than results of urine bioassays collected during the exposure.

PLOS One 16(10): e0259057; 2021 (*Open access*).

USTUR-0571-20

A million persons, a million dreams: A vision for a national center of radiation epidemiology and biology

J. D. Boice Jr.[1,2], B. Quinn[3], I. Al-Nabulsi[4], A. Ansari[5], P. K. Blake[6], S. R. Blattnig[7], E. A. Caffrey[8], S. S. Cohen[9], A. P. Golden[10], K. D. Held[1,11], D. W. Jokisch[12,13], R. W. Leggett[13], M. T. Mumma[2,14], C. Samuels[13], J. E. Till[15], S. Y. Tolmachev[16], R. C. Yoder[17], J. Y. Zhou[4], L. T. Dauer[3]

[1] National Council on Radiation Protection and Measurements, Bethesda, MD
[2] Vanderbilt University School of Medicine, Nashville, TN
[3] Memorial Sloan Kettering Cancer Center, New York, NY
[4] United States Department of Energy, Gaithersburg, MD
[5] Centers for Disease Control and Prevention, Atlanta, GA
[6] Defense Threat Reduction Agency, VA
[7] National Aeronautics and Space Administration Langley Research Center, Hampton, VA
[8] Radian Scientific, LLC, Huntsville, AL, and Risk Assessment Corporation, Neeses, SC
[9]EpidStrategies, a division of ToxStrategies, Inc, Cary, NC
[10] Oak Ridge Associated Universities, Oak Ridge, TN
[11]Massachusetts General Hospital/Harvard Medical School, Boston, MA
[12] Francis Marion University, Florence, SC
[13] Oak Ridge National Laboratory, Oak Ridge, TN
[14] International Epidemiology Institute, Rockville, MD
[15] Risk Assessment Corporation, Neeses, SC
[16]Washington State University, Richland, WA
[17] Landauer, Inc. (retired), Glenwood, IL

Background: Epidemiologic studies of radiation-exposed populations form the basis for human safety standards. They also help shape public health policy and evidence-based health practices by identifying and quantifying health risks of exposure in defined populations. For more than a century, epidemiologists have studied the consequences of radiation exposures, yet the health effects of low levels delivered at a low-dose rate remain equivocal.

Materials and methods: The Million Person Study (MPS) of U.S. Radiation Workers and Veterans was designed to examine health effects following chronic exposures in contrast with brief exposures as experienced by the Japanese atomic bomb survivors. Radiation associations for rare cancers, intakes of radionuclides, and differences between men and women are being evaluated, as well as noncancers such as cardiovascular disease and conditions such as dementia and cognitive function. The first international symposium, held November 6, 2020, provided a broad overview of the MPS. Representatives from four U.S. government agencies addressed the importance of this research for their respective missions: U.S. Department of Energy (DOE), the Centers for Disease Control and Prevention (CDC), the U.S. Department of Defense (DOD), and the National Aeronautics and Space Administration (NASA). The major components of the MPS were discussed and recent findings summarized. The importance of radiation dosimetry, an essential feature of each MPS investigation, was emphasized.

Results: The seven components of the MPS are DOE workers, nuclear weapons test participants, nuclear power plant workers, industrial radiographers, medical radiation workers, nuclear submariners, other U.S. Navy personnel, and radium dial painters. The MPS cohorts include tens of thousands of workers with elevated intakes of alpha particle emitters for which organ-specific doses are determined. Findings to date for chronic radiation exposure suggest that leukemia risk is lower than after acute exposure; lung cancer risk is much lower and there is little difference in risks between men and women; an increase in ischemic heart disease is yet to be seen; esophageal cancer is frequently elevated but not myelodysplastic syndrome; and Parkinson's disease may be associated with radiation exposure.

Conclusions: The MPS has provided provocative insights into the possible range of health effects following low-level chronic radiation exposure. When the 34 MPS cohorts are completed and combined, a powerful evaluation of radiation-effects will be possible. This final article in the MPS special issue summarizes the findings to date and the possibilities for the future. A National Center for Radiation Epidemiology and Biology is envisioned.

International Journal of Radiation Biology 98(4): 795–821; 2022.

USTUR-0574-21

Radium Dial Workers: Back to the Future

N. E. Martinex[1,2], D. W. Jokisch[2,3], L. T. Dauer[4], K. F. Eckerman[2], R. E. Goans[5], J. D. Brockman[6], S. Y. Tolmachev[7], M. Avtandilashvili[7], M. T. Mumma[8,9], J. D. Boice Jr.[9,10], R. W. Leggett[2]

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[3] Department of Physics and Engineering, Francis Marion University, Florence, SC
[4] Department of Medical Physics and Department of Radiology, Memorial Sloan Kettering Cancer Center, New York, NY
[5] MJW Corporation, Inc., Buffalo, NY
[6] Department of Chemistry, University of Missouri, Columbia, MO
[7] U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA
[8] International Epidemiology Institute, Rockville, MD
[9] Department of Medicine, Division of Epidemiology, Vanderbilt Epidemiology Center and Vanderbilt-Ingram Cancer Center, Nashville, TN
[10] National Council on Radiation Protection and Measurements, Bethesda, MD

Purpose: This paper reviews the history of the radium dial workers in the United States, summarizes the scientific progress made since the last evaluation in the early 1990s, and discusses current progress in updating the epidemiologic cohort and applying new dosimetric models for radiation risk assessment.

Background: The discoveries of radiation and radioactivity led quickly to medical and commercial applications at the turn of the 20th century, including the development of radioluminescent paint, made by combining radium with phosphorescent material and adhesive. Workers involved with the painting of dials and instruments included painters, handlers, ancillary workers, and chemists who fabricated the paint. Dial painters were primarily women and, prior to the mid to late 1920s, would use their lips to give the brush a fine point, resulting in high intakes of radium. The tragic experience of the dial painters had a significant impact on industrial safety standards, including protection measures taken during the Manhattan Project. The dial workers study has formed the basis for radiation protection standards for intakes of radionuclides by workers and the public.

Epidemiologic approach: The mortality experience of 3,276 radium dial painters and handlers employed between 1913 and 1949 is being determined through 2019. The last epidemiologic follow-up was 30 years ago when most of these workers were still alive. Nearly 65% were born before 1920, 37.5% were teenagers when first hired, and nearly 50% were hired before 1930 when the habit of placing brushes in mouths essentially stopped. Comprehensive dose reconstruction techniques are being applied to estimate organ doses for each worker related to the intake of 226Ra, 228Ra, and associated photon exposures. Time dependent dose-response analyses will estimate lifetime risks for specific causes of death.

Discussion: The study of radium dial workers is part of the Million Person Study of low-dose health effects that is designed to evaluate radiation risks among healthy American workers and veterans. Despite being one of the most important and influential radiation effects studies ever conducted, shifting programmatic responsibilities and declining funding led to the termination of the radium program of studies in the early 1990s. Renewed interest and opportunity have arisen. With scientific progress made in dosimetric methodology and models, the ability to perform a study over the entire life span, and the potential applicability to other scenarios such as medicine, environmental contamination and space exploration, the radium dial workers have once again come to the forefront.

International Journal of Radiation Biology 98(4): 750-768; 2022.

USTUR-0575-21

. Modelling the long-term retention of plutonium in the human respiratory tract using scar-tissue compartments

D. Poudel[1], M. Avtandilashvili[2], L. Bertelli[1], J. A. Klumpp[1], S. Y. Tolmachev[2]

[1] Radiation Protection Division, Los Alamos National Laboratory, Los Alamos, NM
[2]U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA

The respiratory tract tissues of four former nuclear workers with plutonium intakes were radiochemically analyzed post mortem by the United States Transuranium and Uranium Registries. Plutonium activities in the upper respiratory tract of these individuals were found to be higher than those predicted using the most recent biokinetic models described in publications of the International Commission on Radiological Protection. Modification of the model parameters, including the bound fraction, was not able to explain the data in one of the four individuals who had inhaled insoluble form of plutonium. Literature review points to the presence of-and a significant retention of-plutonium in the scar tissues of the lungs. Accordingly, an alternate model with scar-tissue compartments corresponding to larynx, bronchi, bronchioles, alveolar-interstitium and thoracic lymph nodes was proposed. The rates of transfer to the scar tissue compartments were determined using Markov Chain Monte Carlo analysis of data on urinary excretion, lung counts and post-mortem measurements of liver, skeleton and individual respiratory tract compartments, as available. The posterior models predicted that 20-100%-depending on the solubility of the material inhaled-of the activities retained in the respiratory tract were sequestered in the scar tissues.

Radiation Protection Dosimetry 196(3-4): 167-183; 2021.

USTUR-0592-21

Why "measurand" is the first scientific word we should teach health physicists

D. J. Strom, G. Tabatadze

U.S. Transuranium and Uranium Registries, Washington State University, Richland, WA

The word "measurand" means "the quantity intended to be measured." The authors argue that health physicists should distinguish between measurands and measurement results because the former exist in the domain of theory, while the latter exist in the domain of reality in which we make measurements and observations. The authors demonstrate the importance of separating the quantities used in theory and those used in experiment, clearing up conceptual confusions in three examples of problems routinely encountered in health physics: (1) detection and quantification of radioactive material; (2) multiple definitions of "activity," and (3) the relationship between radiation and health effects. The first

example looks into probabilities of various measurement results (*mi*) given the measurand (*mu*) in comparison with the inverse problem: determining probable values of the measurand (*mu*) based on observed measurement results (*mi*). The second example addresses the distinction between measurands and measurement results given two definitions of activity A provided by the International Commission on Radiation Units and Measurements. Additional consideration is given to use of $N + 1$ counts in (activity) calculations when we have observed N counts, which results from correctly stating and solving the inverse problem. This makes our measurement uncertainties more accurate and our detection decisions more reliable. The last example emphasizes how the observational results of epidemiology, animal experiments, and other radiation biology studies are used to estimate the probability of a particular cancer in an individual-a measurand that is not otherwise accessible to direct observation. Our measurement results, and our use of those results, are more easily understood when we understand the difference between a measurand and a measurement result and can choose the best calculational approach.

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Uncertainty analysis on organ activities and intakes from occupational exposure to plutonium

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The United States Transuranium and Uranium Registries (USTUR) studies the actinide biokinetics and tissue dosimetry in accidentally exposed nuclear workers (volunteer tissue donors). Since 1968, the USTUR has received 313 partial- and 47 whole-body tissue donations. Post-mortem radiochemical analyses of tissues collected at autopsy provide information on long-term retention and distribution of actinides in the human body. These data are accompanied by workers' detailed records on exposure incidents, bioassay monitoring, and medical history. These datasets provide a unique opportunity to evaluate uncertainties in the radiation dose assessment for radiation epidemiology. Among 349 cases with completed radiochemical analysis, 55 cases were selected based on the following criteria: a) at least, five Pu-239 urine measurements exceeding the contemporary detection limit; b) Pu-239 concentrations in the skeleton and liver greater than 0.1 Bq/kg and 1 Bq/kg, respectively, and c) no extensive decorporation therapy. The objectives of this study were to compare: 1) Pu-239 activities in the skeleton and liver predicted based upon urine bioassay with activities measured post-mortem; 2) intake estimates based on the urine data alone with those based on both urine data and post-mortem radiochemical analyses. IMBA Professional Plus® internal dosimetry software was used to fit the super

complex intake regime and to predict organ activity using the ICRP 130 Human Respiratory Tract, ICRP 141 Plutonium Systemic, and ICRP 30 Gastro-Intestinal Tract models. Investigation of 11 individuals, who had worked at the same worksite revealed that the model predictions of Pu-239 activities in organs estimated from urine bioassay differed from the measured values, on average, by 16±36% for the skeleton, and 10±78% for the liver. Intakes calculated using urine data alone differed from those estimated by simultaneously fitting the urine and tissue radiochemical analysis data, on average, by 98±107%.

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Radium Dial Painters: An overview

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Many early discoveries involving radiation and radioactivity found medical or commercial use, with radium a prime example. Marie and Pierre Curie discovered radium in 1898 and soon after radium was being marketed as a medicinal cure-all. It was also quickly discovered that radium could be combined with phosphorescent material to make luminous paint, with related patents filed as early as 1903. The first radium dial watches were sold commercially in 1913, followed by a rapid increase in demand for similar radioluminous products through World War I. Thousands of workers, mainly women, painted dials and instruments with radium paint, using their lips to give the brush a fine point. Although such "tipping" was prohibited in 1926, thousands of women in the US, most of whom were teenagers when they started painting dials, had already spent years licking radium brushes. Being a dial painter was considered glamorous and patriotic, but many dial painters ultimately experienced painful consequences associated with their intakes of radium during work. This tragic experience had a significant historical impact on industrial safety standards, including protection measures taken during the Manhattan Project, and epidemiologic study of the dial painters has formed the basis for radiation protection standards for intakes of radionuclides by workers as well as the public. The study of 3,276 radium dial painters is being updated as part of the Million Person Study (MPS) of low-dose health effects that is designed to evaluate radiation risks among healthy American workers and veterans. This presentation summarizes the history of radium dial painters, presents broad scope information learned to date, and discusses the ongoing follow up work and dose reconstructions that seek to provide new information on the lifetime risk of cancer and other adverse effects of ionizing radiation among women following intakes of radionuclides.

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Dosimetry for a Radium Dial Painter cohort - Past approaches and improvements

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As part of the Million Person Study, work has begun on revisiting and expanding a Radium Dial Painter cohort of 3,276 workers. In the first half of the 20th century, workers manually painted radio-fluorescent paint onto watch and gauge dials. The paint contained Ra-226 and Ra-228 with varying isotopic ratios depending on company, workplace, and year. Workplace practices also varied by individual worker, location, and year. The practice of pointing or 'tipping' the paintbrushes with one's lips was widespread in the United States until the mid-1920s and resulted in significant ingestions of radium paint. Past comprehensive studies were conducted by Massachusetts Institute of Technology, Argonne National Laboratory and other organizations. The current approach builds upon past measurements and calculations of individual radium body burdens which are coupled to the latest biokinetic models to arrive at new estimates of radium intake in the workers. Most dial painters were teenagers or in their early twenties when they began painting. Our current work treats the intakes as chronic over the work period and in and models radium uptake and skeletal development in an age-dependent manner. The current work also explicitly models radioactive progeny in the body. The latest energy absorption models for alpha emitters in the skeleton represent another improvement to past dosimetry calculations. Further, the cohort eligible for dose-response analyses is being expanded by including individuals for whom there was no dosimetry information on record. We discuss methods for estimating doses to such individuals, including uncertainties, based on imputing exposure parameters from contemporary peers performing similar work at the same facilities. This presentation focuses on

doses to the bone and bone marrow. Future work will address doses to other tissues of interest such as the paranasal sinuses, lung, breast, brain and heart.

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USTUR-0576-21A

USTUR Whole-body Case 0680: 53-year follow-up of a Manhattan Project worker

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This whole-body tissue donor to the United States Transuranium and Uranium Registries (USTUR) was occupationally exposed to a mixture of plutonium compounds via chronic inhalation. This individual was one of 26 Manhattan project workers, informally known as 'UPPU (You Pee Pu) Club'. He died 53 years post-exposure. At the time of death, 1,765 Bq of ^{239}Pu was retained in the body, of which 39.7% was in the skeleton, 37.5% in the liver, 16.0% in the respiratory tract, and 6.8% in the remaining soft tissues. Nineteen urine, one fecal, and one blood analysis results as well as four in vivo chest measurements were available. The organ activities at the time of death and bioassay data were used to estimate the intake and radiation doses using the Taurus internal dosimetry software. ICRP recommended biokinetic models adequately described the individual's long-term plutonium retention and excretion. The total cumulative ^{239}Pu intake of 31,716 Bq was estimated; of which, 24,853 Bq (78.4%) were contributed by inhalation of plutonium nitrate and 6,863 Bq (21.6%) of plutonium dioxide. The committed equivalent doses to the red bone marrow, bone surface, liver, lungs, and brain were 0.71 Sv, 6.5 Sv, 8.3 Sv, 3.8 Sv, and 0.068 Sv, respectively. The committed effective dose was 1.22 Sv.

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USTUR-0577-21A

Comparison of two methods to estimate skeletal plutonium concentration from limited sets of bones

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Historically, two calculation methods have been used by the United States Transuranium and Uranium Registries (USTUR) to estimate the actinide skeletal concentration: (i) arithmetic average and (ii) mass-weighted average of concentrations measured in bone samples. Preliminary comparison of skeletal concentrations, estimated for 216 partial-body USTUR cases, using these two methods indicates a statistically significant difference (p <0.05) with the bias of 15% between the estimates. The aim of this research is to determine: (1) which method of skeletal concentration estimate is more accurate for a

given (collected) set of bones and (2) among the sets of bones most commonly collected for partial-body donations, which set provides more accurate estimate of the total skeletal concentration using each method. Nineteen whole-body cases with complete skeleton analyses were used to compare the estimates of the skeletal concentration based on different sets of bones with the concentration based on all measured bones from the right side of the skeleton. Out of 19 cases, ^{239}Pu was a primary radionuclide of exposure for 17, and ^{238}Pu for two cases. Five individuals were diagnosed with osteoporosis. Since osteoporosis significantly impacts plutonium distribution in the skeleton, 19 cases were divided in two study groups – osteoporotic (5) and non-osteoporotic (14). These cases were further sub-divided into 11 bone groups, based on a number of bones (2 to 8) and their frequency of collection at autopsies. These groups represent different balance of cortical- and trabecular-bone-rich bone samples. To compare the two methods, for each bone group, the arithmetic (C_a) and weighted (C_w) average plutonium concentrations were calculated and compared to the total skeleton concentrations (C_{sk}). Preliminary results indicated that, for all cases and all bone groups, both C_a and C_w predict C_{sk} within 10% of the best estimate and C_w yields slightly better estimate of the C_{sk} for non-osteoporotic cases; however, it has a higher uncertainty.

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USTUR-0579-21A

Analysis of long-term retention of plutonium in the respiratory tract of four workers

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Respiratory tract tissues collected from four former nuclear workers involved in various inhalation incidents were analyzed post mortem for plutonium by the United States Transuranium and Uranium Registries. Activities in the upper respiratory tract of these individuals were found to be higher than those predicted using the most recent biokinetic models described in publications of the International Commission on Radiological Protection. An assumption of 'bound fraction' of 0.4-4% was able to explain the data from three workers who had inhaled soluble to fairly insoluble forms of plutonium. For the fourth worker who had inhaled high-fired plutonium oxide, a more insoluble form of plutonium, a mechanism other than bound fraction was required to explain the observed retention of plutonium in the respiratory tract tissues. Literature review points to the presence of – and a significant retention of – plutonium activity in the scar tissues of the lungs. This presentation proposes a human respiratory tract model modified with the addition of scar tissue compartments to describe the long-term retention of plutonium in the respiratory tract of these individuals. The transfer rates between the

compartments were determined using Markov Chain Monte Carlo analysis of the urinary excretion data, lung counts, and post-mortem measurements of the systemic and respiratory tract compartments, as available. The estimates obtained from modeling these data showed that as much as one-third of the total activity in the lung can be sequestered in scar tissues.

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USTUR-0580-21A

Latent Bone modeling approach to estimate plutonium activity concentration in human skeleton

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The skeleton is a major depository site for plutonium in a human body. In radiation protection, a long-term standing question is: What is the most accurate and precise way to estimate the skeleton plutonium concentration and activity from the analysis of a limited set of bones? To answer this question, a multiple linear regression was used in several studies. The key limitation of this approach is multicollinearity among independent variables since the activity concentrations from individual bones are highly correlated resulting in unstable and imprecise estimates of model coefficients. In addition, the number of individual bones allowed in a multiple linear regression model is limited, given a very small number of studied cases. Skeleton plutonium activity concentrations (Bq kg^{-1} of wet bone) for 19 whole-body tissue donors to the United States Transuranium and Uranium Registries (USTUR), were estimated based on post-mortem radiochemical analyses of the right side of the skeleton, where the total number of analyzed bones ranged from 72 to 89. At the USTUR, 87% of deceased Registrants are partial-body tissue donors with only 2 to 8 bones collected at autopsy. For these cases, the most commonly collected bones are rib, sternum, vertebral body, patella, clavicle, and femur middle shaft. This study applied principal components regression (PCR) by performing principal components analysis (PCA) on an analytical data set from 19 whole-body cases, followed by the selection of a set of 1 to 3 principal components as latent bones (independent variables) for a subsequent multiple linear regression modeling. Latent bone concentration (C_{lb}) is not directly measured but is a linear combination of individually measured bone concentrations (C_{bone}). Latent bone concentrations, as independent variables in multiple linear regression, are uncorrelated with each other. For rib, sternum, and vertebral body, PCR analysis resulted in the first latent bone equation: $C_{\mathrm{lb1}} = 0.5759 \times C_{\mathrm{rib}} + 0.5755 \times C_{\mathrm{sternum}} + 0.5807 \times C_{\mathrm{vert}}$. In this case, the first latent bone alone explained 98.4% of total variance, and the skeleton plutonium concentration can be calculated as $C_{\mathrm{skel}} = (18.0 \pm 0.8) \times C_{\mathrm{lb1}} + 25.0 \pm 1.4$.

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Effect of osteoporosis on latent bone models to estimate plutonium activity concentration in human skeleton

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The recently developed latent bone modeling (LBM) approach applies principal components regression (PCR) to estimate plutonium activity concentration in the human skeleton from measurements of a limited set of bone samples. The analytical bone dataset contains plutonium concentrations for 90 individual bone samples from 19 whole-body donors to the United States Transuranium and Uranium Registries. These samples were divided into 6 groups by bone type: skull (11 samples), long bone end (15), long bone shaft (14), cortical bone (29), trabecular bone (18) and other bones (3). Five of 19 studied individuals were diagnosed with osteoporosis. This study evaluated the effect of osteoporosis on LBMs for estimation of skeleton plutonium activity concentrations. For each bone group (except for the mixed bones), the PCR was performed with and without the 5 osteoporotic cases. The PCR models were fitted for 2 to 6 bones randomly sampled from each group, and 10,000 simulations were run for a given number of sampled bones. Regression residual standard error (RSE) for the PCR simulation was used to evaluate model performance. Excluding 5 osteoporotic cases from analyses significantly improved the PCR models in terms of relative RSE reduction compared to those obtained from the analyses of all 19 cases. The average RSEs for 2 to 6 bones were reduced by 60.2±0.4% for trabecular bone, 56.1±5.1% for long bone end, 53.2±1.8% for cortical bone, 48.4±2.4% for long bone shaft, and 22.4±1.9% for skull. Therefore, separate models should be used for non-osteoporotic and osteoporotic individuals when possible. The RSEs of PCR models for non-osteoporotic individuals were 1.9±0.4 for long bone end (epiphysis), 2.5±0.1 for trabecular bone, 2.8±0.1 for cortical bone, 2.8±0.2 for long bone shaft (diaphysis), and 4.2±0.1 for skull. The non-osteoporotic PCR model, accounting for all bone types, was developed by selecting 3 'best' bones with the lowest RSE in each of 5 bone groups. When the analytical dataset for 14 non-osteoporotic cases was reduced from 90 to 18 bones (15 'best' bones plus 3 others), a further improvement of the PCR model fit was achieved with RSE of 1.4±0.4. Due to the limited number of cases, the model to estimate plutonium concentration for osteoporotic individuals was not proposed.

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Uncertainty evaluation of skeleton plutonium activity concentration estimated from a latent bone model

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The recently proposed latent bone model (LBM) for non-osteoporotic individuals applies principal components regression (PCR) to estimate plutonium activity concentration in the human skeleton from measurements of a limited set of bone samples. This study developed a Monte Carlo method to evaluate uncertainty in LBM estimates of skeleton plutonium activity concentration (C_{skel}) using PCR analysis. For this study, the analytical bone dataset was prepared using plutonium concentrations in 18 preselected 'best' bone samples from 14 non-osteoporotic whole-body donors to the United States Transuranium and Uranium Registries. The tissue donors' age ranged from 52 to 87 years and the C_{skel} ranged from 0.9 to 42.0 Bq kg^{-1} of wet weight. The bone set contained 3 samples from each of 6 bone types: skull, long bone end (epiphysis), long bone shaft (diaphysis), cortical bone, trabecular bone, and other bones. The PCRs were used to fit LBMs for 2 to 6 randomly sampled bones, and 10,000 simulations were run for a given number of bone samples. The simulation results indicated that the residuals of plutonium concentrations were normally distributed for each of 14 studied cases. The standard deviation of the residuals (SD) of normal distributions were used to determine the uncertainties associated with the estimated C_{skel}. Linear regression was used to derive a relationship between SD and C_{skel} for each number of sampled bones. The linear regression equations for 2 and 6 sampled bones were: $SD = 0.061\times C_{skel} + 0.846$ ($r^2 = 0.573$, $p = 0.0011$) and $SD = 0.024\times C_{skel} + 0.446$ ($r^2 = 0.398$, $p = 0.0098$), respectively. The higher uncertainties were associated with a lower C_{skel} and a smaller number of sampled bones. As C_{skel} increased, the estimated relative standard deviations (SD/C_{skel}) decreased from 100% to 8% for 2 bones and from 52% to 3% for 6 bones.

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Latent bone modeling approach to select best combination of bones for estimating plutonium activity concentration in human skeleton

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The United States Transuranium and Uranium Registries (USTUR) holds data and bone samples from 290 partial-body tissue donors. Bone samples collected at autopsy were radiochemically analyzed to estimate skeleton activity concentrations of plutonium, americium, and uranium. At the USTUR, the most commonly collected bone samples are rib, sternum, vertebral body, patella, clavicle, and femur middle shaft. Among these, patella, rib, and vertebral body are bones whose collection at autopsy is the easiest. This study applied the recently developed latent bone modeling (LBM) approach to select the best combination of sample bones for estimating the skeleton plutonium activity concentration (C_{skel}). The analytical bone dataset contained plutonium concentrations for the 6 most commonly collected bones from 14 non-osteoporotic USTUR whole-body tissue donors with known Cskel. The LBM models were built for all possible combinations from these 6 bones. The LMB model residual standard error (RSE) was used to determine the best combination of bones. For two bones (15 combinations), RSEs ranged from 1.096 to 4.888 with the best combination being patella and clavicle; for 3 bones (20 combinations), RSEs ranged from 0.853 to 2.557 with the best combination being patella, clavicle, and rib; for 4 bones (15 combinations), RSEs ranged from 0.792 to 2.073 with the best combination being patella, clavicle, rib, and femur middle shaft; for 5 bones (6 combinations), RSEs ranged from 0.970 to 1.382 with the best combination being patella, clavicle, rib, femur middle shaft, and sternum. The LBM RSE for the 3 easy-to-collect bones (patella, rib, and vertebral body) was 1.522. The LBM RSEs for the two bone combinations of these 3 bones were 1.366 for patella and rib, 2.018 for patella and vertebral body, 2.499 for rib and vertebral body. It is worth noting that the patella and rib combination had smaller RSE (1.366) than that of patella, rib and vertebral body (1.522), although, in general, a smaller RSE is associated with a larger number of bones in the LBM.

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