

Final Scientific/Technical Report

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Project Title: Epidemiologic Study of One Million U.S. Radiation Workers and
Veterans

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Executive Summary

The single most important question in radiation epidemiology is determining the level of health risks associated with radiation exposures that occur gradually over time. The study of one million early U.S. radiation workers and veterans has been designed to provide information on risk following chronic exposures by focusing on occupational groups with differing radiation exposure patterns, including intakes of radionuclides. The cost-efficient study builds on the investments made and foundations laid by investigators and government agencies over the past 30-40 years, which have established early worker cohorts that can now provide answers to questions on the lifetime human health risks associated with low-level radiation exposures.

Within the overall goal of the epidemiologic study of one million U.S. radiation workers and veterans, this project had a total of nine specific aims which included studies of six populations for multiple endpoints including cancer overall mortality, leukemia and non-cancer mortality. The six populations included: Mound, Ohio, workers exposed to polonium, tritium and plutonium; nuclear power plant workers within the Landauer dosimetry and Nuclear Regulatory Commission data files; industrial radiographers; Mallinckrodt uranium workers; uranium workers who linked with the US Renal Data System; and nuclear weapons test participants. Over 400,000 workers and atomic veterans are included in these populations, with vital status being determined and analyses of all causes of death undertaken. A critical, integral component of the studies has been comprehensive evaluations of dosimetry involving, in many cases, complex dose reconstructions, and assessments of uncertainties. The work has also involved development of state-of-the art statistical approaches and modeling. All nine aims were accomplished successfully, resulting in publication of two NCRP documents, 13 literature papers, numerous Boice Reports in Health Physics News and many presentations of the work at scientific meetings. Furthermore, recommendations have been developed for an approach to integrate epidemiologic observations with radiation biology for risk assessment and biological models of radiation effect.

The results of this project, as well as ongoing epidemiology studies of US radiation workers and veterans, are providing much-needed insights into complex issues regarding cancer and non-cancer health risks from low dose irradiation, how to apply a "dose and dose rate effectiveness factor" to scale the risks from the A-bomb survivor data to current occupational and environmental circumstances, and how to evaluate risk following intakes of radioactive substances. In addition to application to radiation workers, the results of the studies can provide guidance as society debates the role of nuclear energy and deals with nuclear waste, threats of terrorist attacks with nuclear/radiological devices, the remarkable increase in medical exposures to CT scans and nuclear imaging, and to NASA as radiation protection for astronauts on long-duration mission beyond low-Earth orbit is planned.

Collaborating institutions included: International Epidemiology Institute, Oak Ridge Associated Universities, Oak Ridge National Laboratory, Landauer, Inc., Risk Assessment Corporation, Harvard Medical School, University of Southern California, and Vanderbilt University.

Comparison of Accomplishments with Project Goals and Objectives

Original Specific Aims (from 2012 application)

Specific Aim 1. Mound Ohio Workers. The study of Mound workers exposed to polonium, tritium and plutonium will be published, including a comprehensive evaluation of internal dosimetry.

Accomplishments. Aim 1 was accomplished with the publication of:

Boice JD Jr, Cohen SS, Mumma MT, Ellis ED, Cragle DL, Eckerman KF, Wallace PW, Chadda B, Sonderman JS, Wiggs LD, Richter BS, Leggett RW. Mortality among Mound workers exposed to polonium-210 and other sources of radiation, 1944–1979. *Radiat Res* 181:208–228, 2014.

The publication included a comprehensive evaluation of the internal dosimetry with a focus on the polonium exposures.

Specific Aim 2. Nuclear Power Plant Workers. The vital status and cause of death of over 200,000 nuclear power plant workers will be determined and preliminary results submitted for publication. Incorporation of worker records from early utilities will be sought.

Accomplishments. Aim 2 was accomplished. The cohort of nuclear power plant workers in the United States was identified, and vital status and cause of death determined. Workers from earlier utilities were found within the Landauer dosimetry data files to complement the data obtained from the Nuclear Regulatory Commission. Because of duplicates and selection criteria, i.e., workers had to be employed prior to 1985, the final eligible cohort was of the order of 150,000. Preliminary results were submitted for publication:

Boice JD Jr, Cohen SS, Mumma MT, Hagemeyer D, Chen H, Yoder RC, Dauer LT. Leukemia among early nuclear power plant workers employed between 1957 and 1984 in the United States. (Submitted)

Other relevant publications about the cohort of nuclear power plant workers include:

Bouville A, Toohey RE, Boice JD Jr, Beck HL, Dauer LT, Eckerman KF, Hagemeyer D, Leggett RW, Mumma MT, Napier B, Pryor KH, Rosenstein M, Schauer DA, Sherbini S, Stram DO, Thompson JL, Till JE, Yoder C, Zeitlin C. Dose reconstruction for the million worker study: status and guidelines. *Health Phys.* 2015 Feb;108(2):206-20.

National Council on Radiation Protection and Measurements (NCRP). Deriving Organ Doses and their Uncertainty for Epidemiologic Studies (with a Focus on the One Million U.S. Workers and Veterans Study of Low-Dose Radiation Health Effects). Report No. 178.

National Council on Radiation Protection and Measurements, Bethesda, MD (In press).

Boice JD Jr. Study of U.S. nuclear power plant workers. *Health Phys News* XLI (1):11–12; 2013. Available at <http://ncrponline.org/wp-content/themes/ncrp/PDFs/BOICEHPnews/8-NPP-JAN2013.pdf>.

Specific Aim 3. Industrial Radiographers. The vital status and cause of death of over 50,000 industrial radiographers will be determined and preliminary results submitted for publication. The early (pre1970) microfilmed dosimetry records from Landauer will be computerized to identify early workers and obtain estimates of past radiation exposures.

Accomplishments. Aim 3 was accomplished in that the cohort of 50,000 industrial radiographers (nondestructive testers) was expanded to 138,000 workers on the basis of linkages with the Landauer data files. Estimates of organ specific doses were made. Preliminary analyses for all causes of death were conducted (Standardized Mortality Ratios) and internal dose response analyses for estimates of radiation risk (Cox Proportional Hazards modeling). Preliminary results have been prepared, collaborating with Vanderbilt University and the Oak Ridge Associated Universities. The relevant documents are:

Golden A, Cohen SS, Chen H, Mumma MT, Ellis ED, Boice JD Jr. Statistical Modeling Approaches for Epidemiologic Studies of Low Dose Health Effects. ODRD Report 2017 (prepared for publications).

Bouville A, Toohey RE, Boice JD Jr, Beck HL, Dauer LT, Eckerman KF, Hagemeyer D, Leggett RW, Mumma MT, Napier B, Pryor KH, Rosenstein M, Schauer DA, Sherbini S, Stram DO, Thompson JL, Till JE, Yoder C, Zeitlin C. Dose reconstruction for the million worker study: status and guidelines. *Health Phys.* 2015 Feb;108(2):206-20.

National Council on Radiation Protection and Measurements (NCRP). Deriving Organ Doses and their Uncertainty for Epidemiologic Studies (with a Focus on the One Million U.S. Workers and Veterans Study of Low-Dose Radiation Health Effects). Report No. 178. National Council on Radiation Protection and Measurements, Bethesda, MD (In press).

Specific Aim 4. Mallinckrodt Uranium Workers. Comprehensive dose reconstructions following internal intakes of uranium will be completed and incorporated into a manuscript for publication.

Accomplishments. Aim 4 was accomplished in that complex and comprehensive dose reconstructions for internal intakes of radionuclides were completed and several manuscripts were published or are in press. These manuscripts are

Ellis ED, Boice JD Jr, Kerr G, Golden AP, Girardi D, Cohen SS, Mumma MT, Shore R, Leggett RW. Dosimetry Is Key to Good Epidemiology: Workers At Mallinckrodt Chemical Works Had 6 Different Source Exposures. *Health Phys* (in press 2018).

Boice JD Jr, Cohen SS, Ellis ED, Girardi D, Golden AP, Kerr G, Leggett RW, Mumma MT, Shore R. Low Dose Occupational Epidemiology: The Importance of Dosimetry and Statistics in the Million Worker Study and the Mallinckrodt Chemical Works (MCWL) Cohort. Special Session: 62nd Annual Meeting of the Health Physics Society, Raleigh, NC, July 10, 2017. *Health Phys* 111 (Suppl 11): S38-S40; 2017. Abstracts available at <http://hpschapters.org/2017AM/program/singlesession.php3?sessid=MPM-C>

Boice JD Jr, Ellis ED, Golden AP, Girardi D, Cohen SS, Chen H, Mumma MT, Shore RE, Leggett RW. The Past Informs the Future: The Million Worker Study and The Mallinckrodt Chemical Works Cohort. *Health Phys* (in press 2018).

Specific Aim 5. Uranium Workers. The vital status of nearly 200,000 uranium workers will be determined and linkages with the US Renal Data System completed and a manuscript prepared.

Accomplishments. Approvals were received and linkages with the US Renal Data System, which includes persons who received kidney dialysis or transplants, were completed. These linkages identified serious renal disease for all workers alive after 1976. We have not as yet combined all 200,000 uranium workers for a composite paper but rather published the renal linkage results within individual papers such as:

Boice JD Jr, Cohen SS, Mumma MT, Ellis ED, Cragle DL, Eckerman KF, Wallace PW, Chadda B, Sonderman JS, Wiggs LD, Richter BS, Leggett RW. Mortality among mound workers exposed to polonium-210 and other sources of radiation, 1944-1979. *Radiat Res* 2014;181(2):208-28.

Ellis ED, Boice JD Jr, Kerr G, Golden AP, Girardi D, Cohen SS, Mumma MT, Shore R, Leggett RW. Dosimetry Is Key to Good Epidemiology: Workers At Mallinckrodt Chemical Works Had 6 Different Source Exposures. *Health Phys* (in press 2018)

Specific Aim 6. Nuclear Weapons Test Participants. A manuscript will be prepared describing the cause specific mortality experience of these 115,000 atomic veterans. A case study will be submitted on the 28 weathermen at the Castle Bravo Nuclear Weapons Test in 1954 who received the highest exposure to radioactive fallout of all U.S. nuclear weapons test participants. They were exposed in similar manner as the Rongelap population and the Japanese fishermen on the Lucky Dragon.

Accomplishments. A number of manuscripts have been published regarding the atomic veterans on their dosimetry reconstruction and mortality experience. These include:

Caldwell GG, Zack MM, Mumma MT, Falk H, Heath CW Jr, Till JE, Chen H, Boice JD Jr. Mortality among military participants at the 1957 PLUMBBOB nuclear weapons test series and on leukemia among participants at the SMOKY test. *J Radiol Prot* 2016; 36(3):474-489. Beck HL, Till JE, Grogan HA, Aanenson JW, Mohler HJ, Mohler SS, Voillequé PG. Red bone marrow and male breast doses for a cohort of atomic veterans. *Radiat Res.* 2017;187(2):221-228. Till JE, Beck HL, Aanenson JW, Grogan HA, Mohler HJ, Mohler SS, Voillequé PG. Military participants at U.S. Atmospheric nuclear weapons testing--methodology for estimating dose and uncertainty. *Radiat Res.* 2014;181(5):471-84.

A draft manuscript has been prepared and will be submitted shortly on the 28 so-called weathermen at the Castle Bravo Nuclear Weapons Test in 1954 who received the highest exposure to radioactive fallout of all U.S. nuclear weapons test participants. One focus of this cooperative study with the National Cancer Institute was to contact living veterans and draw blood for chromosome analyses. Because many of these veterans had died, we expanded the

population to include high dose participants at the Nevada Test Site who received > 200 mGy. The base population became 59 veterans of whom 16 were alive and were willing to have blood drawn. The bloods have been analyzed along with control subjects. Comprehensive dosimetry was conducted, including the methods described by Beck *et al.* (2017) and Till *et al.* (2014) above. Standardized Mortality Ratio analyses have been conducted, causes of death determined, and dose response evaluations made of the chromosomal data.

Specific Aim 7. NCRP Report. A comprehensive Report will be completed on the study design, dosimetric and statistical approaches, regulatory implications, and recommendations for an approach to integrate epidemiologic observations with radiation biology for risk assessment and biological models of effect.

Accomplishments. Aim 7 was accomplished with the publication of an NCRP report on the design, dosimetric and statistical approach for the Million Person Study:

National Council on Radiation Protection and Measurements (NCRP). Deriving Organ Doses and their Uncertainty for Epidemiologic Studies (With a Focus on the One Million U.S. Workers and Veterans Study of Low-Dose Radiation Health Effects). Report No. 178. National Council on Radiation Protection and Measurements, Bethesda, MD (In press).

Related works include:

Bouville A, Toohey RE, Boice JD Jr, Beck HL, Dauer LT, Eckerman KF, Hagemeyer D, Leggett RW, Mumma MT, Napier B, Pryor KH, Rosenstein M, Schauer DA, Sherbini S, Stram DO, Thompson JL, Till JE, Yoder C, Zeitlin C. Dose reconstruction for the million worker study: status and guidelines. *Health Phys.* 2015 Feb;108(2):206-20.

Boice JD Jr, Cohen SS, Ellis ED, Girardi D, Golden AP, Kerr G, Leggett RW, Mumma MT, Shore R. Low Dose Occupational Epidemiology: The Importance of Dosimetry and Statistics in the Million Worker Study and the Mallinckrodt Chemical Works (MCWL) Cohort. Special Session: 62nd Annual Meeting of the Health Physics Society, Raleigh, NC, July 10, 2017. *Health Phys* 111 (Suppl 11): S38-S40; 2017.

The approaches to integrate epidemiologic observations with radiation biology were described in another NCRP commentary and a related literature publication:

NCRP Commentary No. 24, “Health Effects of Low Doses of Radiation: Perspectives on Integrating Radiation Biology and Epidemiology” (2015).

Preston RJ. Integrating basic radiobiological science and epidemiological studies: why and how. *Health Phys.* 2015 Feb;108(2):125-30.

Supplemental Specific Aims (added in Sept. 2014)

Supplemental Specific Aim 1. Radiation-related Leukemia among Nuclear Power Plant workers. Among 150,000 nuclear power plant (NPP) under study, 31,200 deaths have been

identified, including 400 deaths due to leukemia. Preliminary dose determinations reveal a broad distribution of doses, with 30,000 workers having <10 mSv career dose estimates and 40,000 workers having >50 mSv career dose estimates. Transient workers who experience non-uniform radiation fields and relatively high doses will be carefully evaluated. Linkages with other dosimetry records such as DOE REMS and military dosimetry systems will be conducted to capture total career dose.

Accomplishments. All items described above were completed and a paper submitted for publication:

Boice JD Jr, Cohen SS, Mumma MT, Hagemeyer D, Chen H, Yoder RC, Dauer LT. Leukemia among early nuclear power plant workers employed between 1957 and 1984 in the United States (Submitted).

Supplemental Specific Aim 2. Non-Cancer Mortality among DOE and other Workers. The overarching aim is to provide quantitative assessment of heart and cerebral vascular disease, and non-malignant respiratory disease among workers at Rocketdyne (Atomics International), Mound and Mallinckrodt. Among the 51,947 workers at Rocketdyne and Mound, there were 6,369 deaths with heart disease listed as the underlying cause, 1,036 deaths from cerebral vascular disease, and 1,235 deaths from non-malignant respiratory disease. Comprehensive dose reconstructions are conducted incorporating both external radiation and internal intakes of radioactive elements in the computation of dose to heart, brain, carotid artery and lung. Pooled analyses of these two cohorts combined with the Mallinckrodt cohort will include contributing as well as underlying cause of death. Other worker studies will be included as they become available, such as Los Alamos, that use the same general methodological approaches to dose reconstruction, disease surveillance and statistical modeling. Atomic veterans might similarly be included as feasible and to the extent possible within the period of performance. Among the 115,000 atomic veterans under study, there were 22,512 deaths with heart disease listed as the underlying cause, 3,149 deaths from cerebral vascular disease, and 6,728 deaths from non-malignant respiratory disease.

Accomplishments. Extensive work and publications have addressed the non-cancer deaths among the DOE worker populations. Heart disease was extensively evaluated among Mound workers, Rocketdyne workers, Mallinckrodt workers and atomic veterans. Rocketdyne workers were combined with Mound workers to learn about the methodologic issues involved in combining diverse populations. Relevant documents and publications include:

Einstein AJ, Sesso HD, Cohen SS, Boerma M, Chambers C, Darby S, Gerber TC, Hirshfeld J, Little MP, Mulrooney DA, Held HD, Boice JD. Classification of cardiovascular causes of death for radiation epidemiologic studies: initial application to cohorts of radiation workers, radiographers, and atomic veterans. European Society of Cardiology Congress 2017, Barcelona, Spain, 26-30 August 2017. Eur Heart J 38 (Suppl_1): P1521, 2017. Available at <https://doi.org/10.1093/eurheartj/ehx502.P1521>

Zhang J, Stram DO, Cohen SS, Pawel D, Sesso H, Boice J. Non-cancer mortality in two radiation worker cohorts (PS7-70). 21st International Meeting – Conference on Radiation Health, Las Vegas, NV, September 2014.

Golden A, Cohen SS, Chen H, Mumma MT, Ellis ED, Boice JD Jr. Statistical Modeling Approaches for Epidemiologic Studies of Low Dose Health Effects. ODRD Report 2017 (in preparation).

Boice JD Jr. Space: The final frontier - research relevant to Mars. *Health Phys.* 2017;112(4):392-397.

Boice JD Jr, Cohen SS, Mumma MT, Ellis ED, Cragle DL, Eckerman KF, Wallace PW, Chadda B, Sonderman JS, Wiggs LD, Richter BS, Leggett RW. Mortality among Mound workers exposed to polonium-210 and other sources of radiation, 1944–1979. *Radiat Res* 181:208–228, 2014.

Summary of Project Activities

The overall goal of the epidemiologic study of one million U.S. radiation workers and veterans is to conduct a mortality study of the early workers of the nuclear age, follow the workers for up to 60 years and evaluate lifetime health effects. Within that overarching goal, this project had a total of 9 specific aims which included studies of six populations (Mound workers, nuclear power plant workers, industrial radiographers, Mallinckrodt workers, uranium workers, and nuclear weapons test participants) for multiple endpoints including overall mortality, leukemia and non-cancer mortality. Critical, integral components of the studies included (1) comprehensive evaluations of dosimetry involving, in some cases, complex dose reconstructions, and assessments of uncertainties and (2) development of statistical approaches and modeling. All 9 aims were accomplished, as described above; this included publication of two NCRP documents, 13 literature papers, listed in the next section and above, as well as numerous Boice Reports in *Health Physics News* and many presentations of the work at scientific meetings, also listed below.

Products Developed under the Award

Publications

NCRP

NCRP Commentary No. 24, “Health Effects of Low Doses of Radiation: Perspectives on Integrating Radiation Biology and Epidemiology” (2015).

NCRP Report No. 178, “Deriving Organ Doses and Their Uncertainty for Epidemiologic Studies (with a focus on the One Million U.S. Workers and Veterans Study of Low-Dose Radiation Health Effects)” in press.

Literature

Boice JD Jr, Cohen SS, Mumma MT, Ellis ED, Cragle DL, Eckerman KF, Wallace PW, Chadda B, Sonderman JS, Wiggs LD, Richter BS, Leggett RW. Mortality among Mound workers

exposed to polonium-210 and other sources of radiation, 1944-1979. *Radiat Res* 2014; 181(2):208-28.

Bouville A, Toohey RE, Boice JD Jr, Beck HL, Dauer LT, Eckerman KF, Hagemeyer D, Leggett RW, Mumma MT, Napier B, Pryor KH, Rosenstein M, Schauer DA, Sherbini S, Stram DO, Thompson JL, Till JE, Yoder C, Zeitlin C. Dose reconstruction for the million worker study: status and guidelines. *Health Phys* 2015;108(2):206-20.

Caldwell GG, Zack MM, Mumma MT, Falk H, Heath CW Jr, Till JE, Chen H, Boice JD Jr. Mortality among military participants at the 1957 PLUMBOB nuclear weapons test series and on leukemia among participants at the SMOKY test. *J Radiol Prot* 2016; 36(3):474-489.

Boice JD Jr. The linear nonthreshold (LNT) model as used in radiation protection: an NCRP update. *Int J Radiat Biol* 2017; 93(10):1079-1092.

Boice JD Jr, Cohen SS, Ellis ED, Girardi D, Golden AP, Kerr G, Leggett RW, Mumma MT, Shore R. Low Dose Occupational Epidemiology: The Importance of Dosimetry and Statistics in the Million Worker Study and the Mallinckrodt Chemical Works (MCWL) Cohort. Special Session: 62nd Annual Meeting of the Health Physics Society, Raleigh, NC, July 10, 2017. *Health Phys* 111 (Suppl 11): S38-S40; 2017. Abstracts available at <http://hpschapters.org/2017AM/program/singlesession.php3?sessid=MPM-C>

Ellis ED, Boice JD Jr, Kerr G, Golden AP, Girardi D, Cohen SS, Mumma MT, Shore R, Leggett RW. Dosimetry Is Key to Good Epidemiology: Workers At Mallinckrodt Chemical Works Had 6 Different Source Exposures. *Health Phys* (in press 2018).

Boice JD Jr, Ellis ED , Golden AP Girardi D, Cohen SS, Chen H, Mumma MT, Shore RE, Leggett RW. The Past Informs the Future: The Million Worker Study and The Mallinckrodt Chemical Works Cohort. *Health Phys* (in press 2018).

Golden A, Cohen SS, Chen H, Mumma MT, Ellis ED, Boice JD Jr. Statistical Modeling Approaches for Epidemiologic Studies of Low Dose Health Effects. ODRD Report 2017 (in preparation).

Boice JD Jr. Space: The final frontier - research relevant to Mars. *Health Phys*. 2017;112(4):392-397.

Beck HL, Till JE, Grogan HA, Aanenson JW, Mohler HJ, Mohler SS, Voillequé PG. Red bone marrow and male breast doses for a cohort of atomic veterans. *Radiat Res*. 2017;187(2):221-228.

Einstein AJ, Sesso HD, Cohen SS, Boerma M, Chambers C, Darby S, Gerber TC, Hirshfeld J, Little MP, Mulrooney DA, Held KD, Boice JD. Classification of cardiovascular causes of death for radiation epidemiologic studies: initial application to cohorts of radiation workers, radiographers, and atomic veterans. European Society of Cardiology Congress 2017, Barcelona, Spain, 26-30 August 2017. *Eur Heart J* 38 (Suppl_1): P1521, 2017. Available at <https://doi.org/10.1093/eurheartj/ehx502.P1521>

Stram DO, Preston DL, Sokolnikov M, Napier B, Kopecky KJ, Boice J, Beck H, Till J, Bouville A. Shared dosimetry error in epidemiological dose-response analyses. *PLoS One*. 2015 Mar 23;10(3):e0119418.

Till JE, Beck HL, Aanenson JW, Grogan HA, Mohler HJ, Mohler SS, Voillequé PG. Military participants at U.S. Atmospheric nuclear weapons testing--methodology for estimating dose and uncertainty. *Radiat Res*. 2014;181(5):471-84.

Boice Reports in Health Physics News

The Boice Report is a monthly column that appears in *Health Physics News*. Perspectives on issues of radiation science, radiation research, radiation guidance, and radiation protection are covered. The Boice Report columns and their titles are available on the NCRP website at <http://ncrponline.org>. Those reports dealing with aspects of the million person study conducted under the grant to NCRP follow.

Boice Report #6, “Study of One Million U.S. Radiation Workers and Veterans: a New NCRP Initiative (DOE Grant Awarded September 2012)”, November 2012.

Boice Report #7, “Study of Atomic Veterans Who Participated at U.S. Aboveground Atmospheric Nuclear Weapons Tests, 1945–1962”, December 2012.

Boice Report #8, “Study of U.S. Nuclear Power Plant Workers”, January 2013.

Boice Report #9, “DOE Worker Studies”, February 2013.

Boice Report #12, “NCRP Dosimetry Committee for the Million Worker Study; Oak Ridge, Tennessee, April 2013”, May 2013.

Boice Report #15, “Low Doses in Madison — July 2013 Health Physics Society Annual Meeting in Madison, Wisconsin”, August 2013.

Boice Report #18, “Health Physics Society/Radiation Research Society Symposium New Orleans, September 2013”, November 2013.

Boice Report #20, “Atomic Bombs, Asbestos, and Healthy Warriors”, January 2014.

Boice Report #26, “The Million Worker Study Comes to Oak Ridge”, July 2014.

Boice Report #33, “How Low Can You Go—Learning to Live With Uncertainty”, February 2015.

Boice Report #37, “The Million Worker Study—From Whence It Came”, June 2015.

Boice Report #45, “From Oak Ridge to Indian Point Studying Workers at Nuclear Power Plants”, February 2016.

Boice Report #55, “The Martian Brain (SC 1-24)”. February 2017

Boice Report #56, “Mallinckrodt Changed the World in 1942”, March 2017.

Boice Report #63, “Cells, Humans and Bill”, November 2017

Other Activities

Scientific presentations included:

“A Study of a Million U.S. Radiation Workers and Veterans.” Division of Cancer Epidemiology and Genetics, National Cancer Institute, Rockville, MD, Sep 6, 2012.

“One million U.S. radiation workers and veterans study.” S8: Radiation-induced Occupational Cancer and Non-cancer Risks: Past, Present and Future perspective, 58th Annual Meeting of the Radiation Research Society, Rio Mar Beach Hotel, Puerto Rico, September 30, 2012.

“Studying one million U.S. radiation workers and veterans.” Epidemiology Grand Rounds, Vanderbilt University, Division of Epidemiology, Nashville, TN, October 9, 2012.

“NCRP and the million worker study.” Interagency Steering Committee on Radiation Standards (ISCORS), Washington, DC, October 23, 2012.

“NCRP and the million worker study,” DOE Nuclear Energy Advisory Committee (NEAC), Washington, DC, December 6, 2012.

“NCRP and the Million U.S. Radiation Worker Study.” Colloquium Lecture, Johns Hopkins University Applied Physics Laboratory, Laurel, MD, Feb 8, 2013.

“Study of one million U.S. radiation workers and veterans.” U.S. NRC Regulatory Information Conference (RIC), Rockville, MD, Mar 14, 2013.

“Study of one million U.S. workers and veterans.” 2013 NCEH/ATSDR Director's Science Seminar Series, Atlanta, GA, May 1, 2013.

“Study of one million U.S. workers and veterans.” The 32nd Annual International Dosimetry and Records Symposium, Scottsdale, Arizona, June 5, 2013.

“A Million US Worker Study.” HPS and ANS Special Session: Issues in Low-Dose Radiation Research. 58th Annual Meeting of the Health Physics Society, Madison, WI, Jul 10, 2013.

“Introduction to the Study of One Million U.S. Workers and Veterans, Symposium, 59th Annual Meeting of the Radiation Research Society, New Orleans, LA, September 15, 2013.

“NCRP and the Million U.S. Radiation Worker Study,” Department of Energy Program Seminar, Forrestal Bldg, Washington D.C., September 23, 2013.

“The million U.S. radiation worker and veteran study,” Colorado Rocky Mountain Chapter of the Health Physics Society (CRMCHPS), Denver, CO, September 26, 2013.

“Studying One Million U.S. Radiation Workers and Veterans: Why, Who, How.” 55th Annual Meeting of the Baltimore-Washington Chapter of the Health Physics Society (BWCHPS), Rockville, MD, May 9, 2014

“Studying one million U.S. radiation workers and veterans. Why, who and how” (Keynote Address). 13th International Workshop on Radiation Damage to DNA. Cambridge, MA, Jun 16, 2014.

“Studying one million U.S. radiation workers and veterans: Why, who and how.” 24th Annual Training and Benchmarking Seminar, MIRION Technologies, Ft. Lauderdale, FL, Jun 19, 2014.

“Epidemiologic studies of radiation workers” (Opening Plenary Session). American Nuclear Society, 18th Topical Meeting of the Radiation and Protection Shielding Division of ANS. Knoxville, TN, Sep 15, 2014.

“NCRP and the Million Worker Study.” U.S. Women in Nuclear. Washington DC, Sep 30, 2014.

“Studying One Million US Radiation Workers and Veterans – Why, Who and How.” Student Advisory Council Lecture, Department of Mechanical, Aerospace, and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy NY, Nov 5, 2014.

“Update on the million worker study,” Interagency Steering Committee on Radiation Standards (ISCORS), Washington, DC, May 27, 2015.

“Million Person Study of Low Dose Radiation Health Effects – Relevance to NASA,” 2016 NASA Investigators’ Workshop; Frontiers in Human Space Exploration Research; Space Radiation Carcinogenesis III & Galactic Cosmic Ray Simulation, Invited Lecture, Galveston, TX, February 9, 2016.

“Million Person Study of Low Dose Radiation Health Effects and the Role of the Center of Radiological Research in Radiation Protection,” Center for Radiological Research Centennial Celebration Symposium, Columbia University, New York, NY, April 28, 2016.

“Update on the Million Worker Study,” Interagency Steering Committee on Radiation Standards, Washington DC, June 23, 2016

“Million Person Study of Low Dose Radiation Health Effects (and Relevance to Space Travel),” The University of Tennessee, College of Engineering, Distinguished Lecturer, Knoxville, TN, October 3, 2016.

“Million Person Study of Low Dose Radiation Health Effects: Relevance to NASA and Radiological Professionals”, Duke Radiology Grand Rounds Series, Duke University, Durham, NC, November 17, 2016.

“Going to Mars (or Not) – Why Research and Dosimetry Matter,” John S. Memorial Lecture, Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, New York, May 22, 2017.

“The Past Informs The Future: The Million Person Study & The Mallinckrodt Chemical Works Cohort,” 62nd Annual Meeting of the Health Physics Society, Raleigh, NC, July 10, 2017.

“An Update of the Million Worker Study,” 2017 NEI Radiation Protection Forum, New Orleans, LA, July 31, 2017.

“Radiation Health Issues when Traveling To Space. Relevance of the Million Worker Study,” 2017 NASA Triennial Health Physics Meeting, NASA Headquarters, Washington, DC, September 12, 2017.

“Radiation Research Relevant to Traveling to Mars”. Epidemiology Grand Rounds. Vanderbilt University Medical Center, Division of Epidemiology, Nashville, TN, November 14, 2017.