

# REACTOR DOSIMETRY

Radiation Metrology  
and Assessment

**JOHN G. WILLIAMS**

**DAVID W. VEHAR**

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Editors



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John G. Williams, David W. Vehar, Frank H. Ruddy,  
and David M. Gilliam, editors

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The Tenth International Symposium on Reactor Dosimetry was held in Osaka, Japan on 12-17 Sept. 1999. ASTM Committee E-10 on Nuclear Technology and Applications served as its sponsor. Appendix I lists the symposium organization, other sponsors, and acknowledgments. Appendix II is a list of the symposium attendees and their addresses.

The symposium chair and co-editor of this publication was Frank H. Ruddy, Westinghouse Science & Technology Ctr. Also serving as editors were John G. Williams, University of Arizona; David W. Vehar, Sandia National Laboratories; and David M. Gilliam, National Institute of Standards & Technology.

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*The Editors and the participants in the International Symposium on Reactor Dosimetry remember with gratitude the lives and the contributions to the symposia of Art Lowe and Natasha Markina*

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**Arthur L. Lowe, Jr., 1927–1999**

Our friend Arthur (Art) Lowe of Lynchburg, Virginia, U.S.A., died on December 27, 1999. His engineering career started in 1951, prior to joining the Babcock and Wilcox Company in 1957. After more than 36 years of service, he retired from Babcock and Wilcox in 1994 but continued his professional work as a private consultant. He also continued his long service to the American Society for Testing and Materials, where, for more than 30 years, he was an active member of Committee E10 on Nuclear Technology and Applications. His special expertise and accomplishments were in the application of materials for nuclear fuel cladding and reactor internals, in the development of the reactor vessel surveillance program, and in the evaluation of radiation effects on materials. In 1997 he received the Peter Hedgcock Award in recognition of his distinguished service to ASTM Committee E10. Art was very well known to participants of the International Reactor Dosimetry Symposia, which he had served from its earliest meetings as technical contributor and author and also, for nearly 20 years, as a member of the ASTM Symposium Committee. Although unable to attend the Tenth Symposium in Osaka, he had been fully involved in the planning of organizational and technical matters for the meeting. He was loved and respected by his colleagues in the United States and elsewhere for his originality, good humor, and consistent dedication to serious and practical work.

**Natalia V. Markina, 1941–1999**

We lost our friend and colleague Dr. Natalia (Natasha) Markina, who died of a heart attack on February 2, 1999. From 1963 to 1965, Natasha worked at the Instruments Factory in Lvov (Ukraine), and from 1965 until her death she worked at the Research Institute of Atomic Reactors (RIAR) in Dimitrovgrad (Russia), where she progressed from assistant scientist to become Head of the Neutron Metrology Laboratory, which she founded. Natasha was a scientific secretary of the Russian Coordination Committee on Metrology of Materials Testing, a member of the Russian Nuclear Society, and a member of ASTM. The main focus of her work was in the field of reactor testing of materials, and metrology in support of testing. Natasha actively participated in solving many problems, including in-reactor temperature measurements, development of testing methods, technology and devices, creation of the Russian catalog of testing methods and facilities, dosimetry for reactor testing, and dosimetry certification of RIAR reactors and irradiation devices. She also was responsible for creating the KORPUS facility for radiation testing of RPV materials, and for its dosimetry certification. Natasha organized international collaboration and interlaboratory comparisons at the KORPUS facility. Participants from Russia, Bulgaria, Germany, Belgium, Netherlands, and Finland remember an interesting and fruitful collaboration, and also the hospitality and the atmosphere of friendship and patience created by Natasha. She was born in Odessa, on the Black Sea coast, and like this town, Natasha was sunny and friendly with a unique sense of humor. As a trusted friend, ready to help anyone in need, Natasha was admired by everyone who knew her.



# Overview

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The papers in this volume were presented at the Tenth International Symposium on Reactor Dosimetry (ISR D), held in Osaka, Japan. Included are three invited keynote papers, and one hundred contributed papers arranged in seven sections that cover the technical scope of the Symposium. Preceding these, an article entitled "Summaries of Workshops Meetings" provides brief reviews of the status of nine technical areas discussed by participants.

The subjects of the nine workshops were: radiation damage correlations, irradiation dosimetry at test and research reactors, thermal and low-energy neutron dosimetry, light water reactor (LWR) surveillance and retrospective dosimetry, fusion and high-energy neutrons, cross sections and uncertainties, benchmarks and intercomparisons, mixed field dosimetry, and adjustment methods and uncertainties. The summaries include some consensus statements concerning the status of each topic, as discussed at the Symposium.

The keynote papers begin with the question, "Why do we need dosimetry?" asked and answered in a paper with that title by Gerard and Zaritsky, who discuss surveillance and lifetime assessment for power reactor vessels and internals. The second keynote paper, by Griffin, describes the role of ASTM Committee E-10 on Nuclear Technology in promoting standards for Reactor Dosimetry and the scope of the existing ASTM standards in this field. The third keynote paper, by Kimura, provides a review of reactor dosimetry activities in Japan, the host country for the Tenth ISR D. Spanning most of the scope of this volume, the workshop summaries and the keynote papers provide a good introduction to the detailed technical papers that follow.

The first section of contributed papers contains seventeen articles covering the subject of power reactor surveillance. There are papers on reactor vessel surveillance for pressurized water reactors (PWRs) in France, United Kingdom, Korea, Japan, and the United States; for VVERs in Russia, Czech Republic, Ukraine, Bulgaria, and Hungary; for a heavy water reactor in Argentina; and for MAGNOX reactors in the UK. In addition there are three papers on assessment of concrete structures outside reactor vessels. Also included in this section is a paper on the assessment on neutron fluence uncertainty and its impact on safety issues for reactor vessels.

The next section contains sixteen articles on dosimetry for test reactors and accelerator sources. Topics include facilities for such applications as boron neutron capture therapy (BNCT), semiconductor testing, structural steel testing, and nuclear fuel testing in a variety of types of reactor and accelerator neutron sources. Development of new facilities and improvement of existing facilities and methods are included.

The section on Benchmarks and Intercomparisons contains eleven articles on experiments and analysis used to test and improve techniques and data, by means of standards and calibrations and specially designed reference fields. One of the papers in this section, on "Adjustment of the  $^{235}\text{U}$  fission spectrum," shared the Best Paper Award for papers presented in poster sessions.

The section on Cross Sections and Nuclear Data includes eleven papers on cross section measurements and evaluations and on compilation and testing of cross section libraries. Measurements reported include: high energy neutron activation cross sections, new measurements of the  $\text{H}(n,n)\text{H}$  angular distribution, fission cross sections of  $^{229}\text{Th}$  and  $^{231}\text{Pa}$ , neutron-induced charged-particle emission cross sections for 5-75 MeV neutrons, fast neutron yields from deuteron break-up in low energy reactions of light nuclei, and capture cross

sections for dysprosium and hafnium. Four papers discuss dosimetry data libraries and their integral testing. These include the revised JENDL Dosimetry File and SPALDOS, a library for use at spallation sources.

The Section on Calculations and Adjustment Methods contains fourteen articles. Seven of these are concerned with neutron transport codes for modeling LWR vessels and internal structures. Monte Carlo and three-dimensional discrete ordinates methods are both well represented. Two papers in this section describe computational methods for estimation of induced activity in ex-vessel components. The remaining five papers discuss neutron spectrum adjustment methods, including spectrum representation and the representation of uncertainties. One of these, by Perel et al., describes the theoretical justification for several "oral laws."

There are ten articles in the section on Damage Correlations and Damage Dosimetry. Four of these deal with calculation of displacements-per-atom (dpa), kerma, and atomic-recoil energy spectra, and data libraries derived for these. A paper by Yoshiie et al. discusses the use of primary knock-on atom (PKA) spectra for prediction and correlation of property changes (damage) in reactor structural materials. Three other papers in this section also discuss damage mechanisms in steels and the correlation of damage with exposure parameters for both neutrons and gamma rays. One paper describes measurements and Monte Carlo modeling of damage in electronic materials for fusion reactor sensors. The section concludes with two papers on European and U.S. programs, respectively, for generation of database information for prediction of pressure vessel degradation and embrittlement.

The final section, on Experimental Techniques, includes twenty-one articles, divided approximately equally between active detector techniques (eleven papers), including spectrometers and instruments for in-core monitoring, and passive irradiation monitoring (ten papers), including activation monitoring methods. Four of the papers on in-core monitoring describe optical fiber techniques developed in Japan. Other optical and scintillator methods used for spectrometry and imaging are described in three papers. One paper deals with self-powered detectors, and another discusses these and miniaturized fission chambers for in-core monitoring. The paper by Blandin, Bignan, Guyard, and Lebrun shared the Best Paper Award for papers presented in poster sessions. There are eight papers on activation monitoring and activity measurement methods, including gamma spectrometer calibration, counting of very low activity levels,  $^{93}\text{Nb}(n,n')$  reaction rate measurements, the use of spectral indices, and accreditation and certification of activity measurements. There is one paper on a plastic track-etch detector technique and one on electron spin resonance (ESR) sensors. Finally, a new method of on-line monitoring of boron concentration in reactor coolant is described.

The volume includes, at the end, keyword and author indices and an address list for the Symposium participants.

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# History

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Important advances have been made over the past three decades in neutron and gamma-ray physics and dosimetry. These advances have generated new analysis and measurement techniques, lessened uncertainties, and produced standards for international use. Most of this development has been done in support of reactor development programs and the enhanced understanding of radiation damage to reactor fuels, materials, and components. An important contribution to these activities has been a series of successful symposia that have brought together leading experts from around the world.

The first *ASTM-Euratom Symposium on Reactor Dosimetry*, which took place in 1975 at the Joint Research Centre, Petten, The Netherlands, generally defined the status of reactor neutron metrology and damage-analysis programs and identified the needs of the nuclear power industry. The second symposium, hosted in 1977 by the Electric Power Research Institute, Palo Alto, California, emphasized data and techniques used to characterize neutron and gamma-ray environments, including the use of well-characterized benchmark fields. The third meeting, in 1979 at the Joint Research Centre, Ispra, Italy, focused on the interactions between materials experts and dosimetry metrologists. The thrust of the next two symposia, at the National Bureau of Standards, Washington, D.C. in 1982 and at the GKSS Research Centre, Geesthacht, Germany in 1984, was radiation metrology techniques, data bases, damage correlation analyses, and standardization. However, a growing number of papers were concerned with reactor pressure vessel surveillance techniques and correlation of the resulting data, reflecting a progression from test reactor research to applications in a maturing power reactor industry.

The sixth and seventh symposia, held in 1987 at Jackson Hole, Wyoming, and in 1990 in Strasbourg, France, again covered reactor dosimetry and dosimetry standardization. There was major input on light water reactor pressure surveillance work and on dosimetry in support of plant life extension. Progress was reported on multinational joint research projects designed to improve the accuracy of pressure vessel dosimetry and the accuracy of materials property trend curves by performing interrelated experiments in a number of well-characterized neutron fields. The technical community concerned with dosimetry for radiation effects in electronics was also strongly represented.

The *Eighth ASTM-Euratom Symposium on Reactor Dosimetry*, held in Vail, Colorado in 1993 provided an update of the field of reactor dosimetry. Experts were specifically invited to discuss their latest results under the broad theme of dosimetry for the correlation of radiation effects. Increased participation in the symposium by experts from central and eastern Europe resulted in several papers on the status of surveillance programs in these countries.

The ninth symposium was held in Prague, The Czech Republic in 1996. Renamed the *Ninth International Symposium on Reactor Dosimetry*, this symposium marked an increased attendance from the former Soviet Union republics. Notable also was the increased participation by experts from Japan, and the large number of papers on Japanese surveillance dosimetry, materials property changes under irradiation, and related research reactor programs.

The *Tenth International Symposium on Reactor Dosimetry*, held in Osaka, Japan from September 12–17, 1999 is the subject of the present volume. Organized under the theme “dosimetry for the assessment of irradiated reactor materials and reactor experiments,” this



symposium was the first in the series to be held in a venue other than Europe or the United States and resulted in a record attendance of 148. In addition to attendance from Europe and the United States and continued strong participation from the former Soviet republics, increased participation from Japan and other Pacific Rim nations resulted. The Osaka symposium demonstrated that interest in the field of Reactor Dosimetry is continuing to grow, and that work in this area has truly become international.

The *Eleventh International Symposium on Reactor Dosimetry* is scheduled to be held in Brussels, Belgium from August 18–23, 2002.