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Recent Dosimetry Activities at the NIST

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1. INTRODUCTION

The following is intended as a general overview of activities by the Radiation Interaction and Dosimetry Group, Ionizing Radiation Division, National Institute of Standards and Technology (NIST), USA, to the meeting of Section I (X and ? rays, electrons) of the Consultative Committee on Ionizing Radiation (CCRI), May 23-25, 2001, Paris. The material was taken from more extensive information gathered for NIST program reviews, and covers roughly calendar years 1999 and 2000. Our technical activities are summarized in Section 2, and staff members involved in each project are identified. Section 3 gives recent publications by the Group, and Section 4 gives information to contact staff members.

2. TECHNICAL ACTIVITIES{TE \l 1 "TECHNICAL ACTIVITIES"}

A. Theoretical Dosimetry

Computational Radiation Transport and Dosimetry. With a new staff position recently filled by a research physicist, expert and experienced in the development of radiation interaction cross sections and in Monte Carlo development, the Radiation Interactions and Dosimetry Group and the Photon and Charged Particle Data Center have begun a more vigorous program in the development of data and codes, and in their use, to address needs in computational radiation transport and dosimetry. Current topics include the development of a new database of photon interaction cross sections, the investigation of wall effects in graphite-cavity ionization chambers, the investigation of scattering effects by beam-modifying absorbers in our standard gamma-ray sources, and the installation of a number of the widely used general-purpose Monte Carlo codes for local use. The goal is to build to a program for the development of state-of-the-art Monte Carlo methods and cross sections to address the growing needs in, and reliance on, radiation transport simulation. (S.M. Seltzer, P.M. Bergstrom)

Photon and Charged-Particle Data Center. The Data Center compiles, evaluates, and disseminates data on the interaction of ionizing radiation with matter. The data on photons and charged particles, with energies above about 1 keV, include fundamental information on interaction cross sections as well as transport data pertaining to the penetration of radiation through bulk material. Databases are developed and maintained on attenuation coefficients for x rays and gamma rays, including cross sections for Compton and Rayleigh scattering, atomic photo-effect, and electron-positron pair production, as well as on energy-transfer, energy-absorption and related coefficients relevant to radiation dosimetry. Work on charged-particle cross sections and of radiation transport data has entailed significant effort on the evaluation of the stopping powers and ranges of electrons, positrons, protons, and alpha particles, the elastic scattering of electrons and positrons, and the cross section for the production of bremsstrahlung by electrons. (S.M. Seltzer, P.M. Bergstrom, J.H. Hubbell, M.J. Berger)

Compton Scattering of Photons. The availability of high-speed computing devices on the desktop has enhanced the applicability of Monte Carlo transport methods. Many of these new applications such as radiation treatment planning, detector modeling and radiography require modeling at lower and lower energies for accuracy. At these low energies, there is an increased need for differential cross section data for Compton scattering of photons from bound electrons. The Photon and Charged Particle Data Center is developing an inelastic-photon-scattering database that will provide such differential data, as well as a consistent set of integrated cross-section data. The approach we are taking is based on the impulse approximation, the most widely used method of accounting for the main contributions to the Compton scattering cross section. We have utilized the impulse approximation to develop a number of sets of differential scattering data (Compton profiles) that enable the calculation of the cross section, doubly differential in scattered photon energy and angle, for all elements up to Xenon. We are in the process of utilizing these databases to understand the sensitivity of the Compton profile to the various atomic models employed in their derivation. Further, we are quantifying the applicability of the Compton-profile approach to the impulse approximation. Once these analyses are complete, a tabulated set of Compton scattering data will be available with an enhanced understanding of the theoretical uncertainties. These data will then be utilized to provide consistent total cross-section and energy-absorption coefficient databases. (P.M. Bergstrom, J.H. Hubbell, S.M. Seltzer)

Cross Sections for the Elastic Scattering of Electrons and Positrons by Atoms. A new evaluation of cross sections for the elastic scattering of electrons and positrons by neutral atoms has been completed. Results are given for atomic numbers Z = 1 – 100, and for kinetic energies from 1 keV to 100 MeV. For energies up to 10 MeV, the results are obtained from the code of Riley, which calculates phase shifts by the numerical solution of the Dirac equation. Screened Coulomb potentials, used as input, were derived from electron density distributions obtained with the Dirac-Hartree-Fock code of Desclaux. Above 10 MeV a new code was developed that uses the same electron density distributions as input, but is based on the WKB method of Molière as formulated by Zeitler and Olsen. The output tables include differential cross sections at 314 angles, at 61 energies for electrons, and at 41 energies for positrons. Total and first transport cross sections are also included. The basic tabulations are for scattering by free atoms with point nuclei, and neglect exchange and polarization effects. Cross sections for many elemental solids are also tabulated which were obtained with free-atom potentials modified according to a prescription of Raith. Also tabulated are correction factors that take into account (a) the exchange effect for incident electrons (according to an approximation of Riley), and (b) the reduction of the cross sections at high energies and large deflection angles, assuming a nuclear charge distribution according to the Fermi model rather than a point nucleus. An interpolation program is provided that can be used to generate cross sections at any energies and angles specified, for gases or solids, with or without the corrections (a) and (b). A code is also provided which generates transport cross sections of arbitrarily high order needed as input for the calculation of Goudsmit-Saunderson multiple-scattering angular distributions. (M.J. Berger, S.M. Seltzer)

Proton and Alpha Particle Stopping Powers. Our work on the critical evaluation and the preparation of databases of proton and alpha particle stopping powers and related quantities was incorporated into Stopping Powers and Ranges for Protons and Alpha Particles, Report 49 of the International Commission on Radiation Units and Measurements, 1993. Those results were recently criticized by another database producer in the journal Radiation Research as defective in a number of respects. After a thorough analysis and detailed comparisons, it has been demonstrated that the criticisms are largely erroneous and that the data hold up better than the competing database. A Letter to the Editor documenting this conclusion has been published in Radiation Research. (S.M. Seltzer, M.J. Berger)

Theoretical Dosimetry for Brachytherapy Sources. Brachytherapy sources, encapsulated radioactive material emitting photon and/or beta particles, are used in a variety of therapeutic applications. Such sources include ophthalmic applicators for the treatment of ocular lesions, low-energy photon "seed" implants for the treatment of prostate cancer, and photon- and beta-emitting intravascular sources of various design intended for the irradiation of artery walls to prevent re-closing (restenosis) after balloon angioplasty. Numerous calculations have been done for a wide variety of source designs to determine the spatial distribution of absorbed dose per unit activity in the source to aid in source optimization, to provide basic dosimetric data, and to determine correction factors for measured results. These calculations are done with state-of-the-art Monte Carlo codes, such as ITS, MCNP4b, and EGS4, and with more rapid point-kernel-based calculations. (S.M. Seltzer, C.G. Soares)

B. Industrial Dosimetry

Accelerator Radiation Sources. Our electron accelerator facilities continue to support active research in radiation interaction studies. These electron sources include the 32 MV linear accelerator of the Medical and Industrial Radiation Facility (MIRF), the 4 MV Van de Graaff accelerator, and the 500 kV cascaded rectifier electrostatic accelerator. NIST electron beams are used in a broad array of applications including materials modification, detector calibration and characterization, radiation-hardness studies, production of radioisotopes, radiation treatment of wastewater, and medical and industrial dosimetry. These machines allow us to provide research beams ranging in electron energy from 10 keV up to 32 MeV. This variability in beam energy gives us a unique capability found at few other facilities. Our present efforts include characterizing and refining beam delivery on the 500 kV accelerator to support studies in electron beam dosimetry for radiation-processing applications, in materials research and in detector characterization. We are continuing to develop a high-energy x-ray computed tomography system at the MIRF that will be used to refine techniques and procedures for industrial imaging. Our future plans include a program to measure the low-energy response of radiochromic and alanine routine dosimeters using the 500 kV accelerator. Emphasis will be placed on developing standards for low-energy electron-beam dosimetry based on calorimetric methods. This will help us to provide guidelines and standards for the radiation processing industry. We will also work to develop high-energy e-beam dosimetry standards using graphite calorimeters with the MIRF linear accelerator. (F.B. Bateman, M.R. McClelland)

Internet-Based Calibration Services for the Radiation-Processing Industry. In cooperation with industry, academia and other government agencies, an Internet-based system will be built for fast remote calibration of high-dose radiation sources against the U.S. national standard gamma-radiation source. The project has been facilitated by the National Advanced Manufacturing Testbed (NAMT) based in NIST's Manufacturing Engineering Laboratory. The new service will deliver immediate calibration results to the industry customer on-demand at a lower cost. The industrial site will have a dosimeter reader and an Internet link to the NIST server. When a calibration is requested, the industrial site logs into the NIST calibration web site and initiates the process. In order to ensure a reliable dose assessment, the NIST server will lockout the local user and fully control the measurements remotely. The remote-control process will include the spectrometer calibration, setting of readout parameters, and initiating the spectral acquisition. The post-measurement evaluation process involves a rigorous verification of the quality of the acquired spectra, and employs dose calculations from calibration curves maintained at NIST. The system has been demonstrated at national and international dosimetry symposia. NIST is now negotiating with industry partners who will begin to field-test the system. This Internet-based transfer calibration process will be the most modern calibration service available and offer many options for expansion into other areas of dosimetry and metrology in general. (M.F. Desrosiers, V. Nagy, J.M. Puhl)

Short-Term Effects of Humidity on Alanine Dosimeter Response. Studies on the influence of storage/readout humidity on Bruker and on NIST alanine dosimeters were completed. The long-term effects of storage humidity were monitored for one year at three doses and six humidities, and were consistent with previously published data on other systems and will prove particularly useful to the NIST calibration service. Short-term changes in the amplitudes of alanine EPR signals were measured immediately after removal of the pellets from a controlled humidity environment. In the case of pellets just removed from the 0% humidity desiccator, the alanine signal amplitude noticeably decreases for at least 5 hours, and the decrease during the first two hours is particularly significant. The amplitude of the ruby reference signal decreases accordingly; these changes reflect the Q-factor decrease with time due to the process of absorbing humidity from the laboratory (about 30-40% R. H.). If storage humidity is relatively high (44%, 57%, 75%, and 94% R. H.), the absolute amplitude of the alanine signal increases during the first hours after entering the EPR laboratory environment; so does the amplitude of the ruby signal. This reflects the process of pellet drying in the cavity. The greater the initial moisture content of the pellet, the stronger is the signal increase in time. If the storage humidity (33%) is close to the laboratory humidity, the changes in alanine signal amplitude are very small. It should be noted that normalization to the ruby amplitude keeps the alanine signal constant within 0.2% of its initial value regardless of these drying/wetting processes. A third alanine dosimeter source is being employed for use in the NIST transfer dosimetry service. Gamma Service of Germany offers alanine dosimeters in film and pellet form that appear very uniform with high precision. Testing has begun on the effects of storage humidity on the film-dosimeter response; early results indicate that they are relatively insensitive to humidity. A study of short-term changes in the amplitudes of alanine-EPR signals has been completed. These results, coupled with the long-term fading of the EPR signal and the complications from cavity Q-factor instability due to varying moisture content of some pellets, make it undesirable to use “standard” irradiated alanine pellets for monitoring variations in sensitivity of EPR spectrometers. It is recommended that the practice of using “standard” irradiated alanine pellets for monitoring variations in sensitivity of EPR spectrometers be discontinued. (O. Sleptchonok, V. Nagy, M.F. Desrosiers, J.M. Puhl)

Temperature Stabilization of Alanine Dosimeters. The alanine dosimeter response has a small but noticeable temperature dependence, and the dosimeter temperature during irradiation must be measured to obtain the highest degree of accuracy. However, it is difficult to reliably measure the temperature of the alanine dosimeters during irradiation, and the uncertainty in dose measurements due to this effect can be very significant. An alternative approach may be to stabilize the temperature of the dosimeters to a pre-determined value. We have constructed a small (200-300 cm^3) thermostat containing water-ice mixture. The temperature of this mixture remains at 0ºC during the irradiation session; the dosimeters are placed in a small container within the thermostat. The results indicate that the thermal characteristics of foam plastic thermostats and glass dewars are more than sufficient for temperature control during the irradiation process. The procedure described here can decrease the irradiation temperature uncertainty contribution to the total dose uncertainty by an order of magnitude for irradiation conditions where the measurement of temperature during irradiation is not possible or inherently inaccurate. (V. Nagy, A. Bougai, M.F. Desrosiers, K. Mehta)

Monte-Carlo Simulations of Regression Techniques. A software package has been developed to simulate regressions used in EPR dosimetry under conditions when standard assumptions of the least-squares technique (insignificant errors in *x*, independence of errors in y at different xs, a normal distribution of errors in y, a constant standard deviation of y over the calibration range) are not valid. These programs made it possible to estimate real uncertainties in the doses determined in various complex situations, where closed analytical expressions for uncertainties are not available. Application of these programs to an analysis of the techniques currently used in EPR tooth dosimetry revealed the real magnitude of the uncertainties in reconstructed doses and their dependence on the experimental design. Ways to considerably optimize these techniques by decreasing the labor and increasing the accuracy of reconstructed doses have been found. The program has now been expanded to simulate curvilinear calibration curves with errors both in *y* and *x* (Lisy algorithm). (V. Nagy)

Alanine-EPR Film Dosimeter. A new polymer-based film dosimeter containing alanine has been tested. The film, obtained from Gamma Service (Germany), is produced in commercial quantities in a variety of thicknesses. The first films tested were 100 µm in thickness and irradiated over a range of 1 kGy to 100 kGy. The relative standard deviation of the response over this range was on average 0.8%. The EPR signal at 1 kGy was measurable but required enhancement to obtain a signal-to-noise level comparable to 2 kGy and above. Comparative measurements of radiochromic films and alanine films irradiated at MIRF produced similar dose values within the relative uncertanities of the two systems. The two systems correlated best at 10 kGy; alanine outperformed the radiochromic films at 1 kGy (despite this being the weakest response of the alanine series). A more comprehensive study of the alanine system is planned.

A small batch of 10 µm alanine films was recently received and will be tested for use with low-energy electron beams. (M.F. Desrosiers, J. Puhl, F.B. Bateman, M.R. McClelland)

Calibration of Low-Energy Electron Beams. A NIST-industry working group has been formed to develop calibration methods for low-energy electron beams (<500 keV) in accordance with the guidance requirements of the American National Standard ASTM E 1261-00 (Standard Guide for the Selection and Calibration of Dosimetry Systems for Radiation Processing). The only method available to a commercial user is to irradiate the dosimeters off-site at an accredited calibration facility with no means of performing the required on-site verification. This results in a potentially large (Type B) uncertainty. Moreover, the calibration facility irradiates the dosimeters at high energies (^{60}Co gamma rays or ~10 MeV x rays), and uses that dose response as a calibration curve for determining the dose of routine dosimeters used for low-energy electron beams, thereby incurring the uncertainty associated with possible energy and particle-type dependence of the dosimeter response. In-situ calibrations utilizing 10 mm alanine film from NIST, in conjunction with industrial routine dosimeters, will be aimed at establishing a calibration service for this industry group. (M.F. Desrosiers, J.M. Puhl, V. Nagy)

General-Purpose Concentration Standard for EPR. Work continues on creating a standard reference material for determining absolute numbers of paramagnetic centers in various samples. A reference material is needed in many EPR applications in materials science, physics, chemistry, biology, medicine, geology, and other areas. The concentration of the paramagnetic centers has been reliably determined in a suitable material by two independent high-precision analytical techniques unrelated to magnetic resonance and magnetism in general. This standard reference material will make it possible to determine concentrations of almost any paramagnetic species on the basis of our previously compiled tables of specific intensities of EPR signals from paramagnetic centers of different types. Current activities involve the long-term monitoring of the EPR signal stability. (V. Nagy, M.F. Desrosiers)**{**PRIVE **}**

X-Ray Measurement Quality Assurance for DoD Large-Motor Inspection Facilities. For the past 20 years NIST personnel have provided x-ray measurement and radiographic expertise in support of the Navy's large missile motor inspection programs. Part of this function involves the development and manufacture of image-quality indicators used during the inspection process to set the minimum level of image quality necessary for the inspection to be considered valid and acceptable. A parallel function involves the measurement of the output of the x-ray generators at the multiple inspection sites to document equivalency of the inspection sources. The x-ray energy used for component and motor inspections at these sites range from 420 kVp to 16 MeV. NIST personnel have developed and maintained a computer-based portable measurement system referenced to the NIST standard ^{60}Co teletherapy beam to perform such measurements. NIST also provides consulting service to DoD's Integrated High Payoff Rocket Propulsion Technology Program in the development of a high-resolution 3-D computed-tomography imaging system. Approximately 90% of the acceptance test procedures have been completed on this state-of-the-art inspection system. (J.H. Sparrow)

C. Medical Dosimtery

Calibration Service for Radiotherapy Beams. One of our prime functions is the transfer of dosimetric standards for external beam radiation therapy. The standard has been air kerma in ^{60}Co gamma-ray beams, which could be converted to absorbed-dose-in-water for a clinical beam (usually high-energy x rays from a linear accelerator). Currently, North America and the international measurement system is moving to a standard of absorbed-dose-to-water from ^{60}Co gamma-ray beams, largely made possible by the development of water calorimeters in which NIST was the leader. Such a change is intended to simplify and reduce uncertainties in the determination of absorbed dose in radiation therapy. NIST is now transferring its absorbed-dose standard through a network of secondary calibration laboratories. In support of our calibration service for radiotherapy beam dosimetry, NIST has purchased a new 12 kCi, ^{60}Co source whose beam is currently being fully characterized. When completed, the new beam will be carefully calibrated using national standards for both air kerma and absorbed-dose-to-water. (J. Shobe)

Proficiency Testing to Support Clinical Cancer Dosimetry. The American Association of Physicists in Medicine (AAPM) has promulgated a new protocol to improve the dosimetry for gamma-ray, x-ray and electron beams used for cancer therapy, one based on absorbed-dose-to-water. In 1997, NIST, in collaboration with AAPM Task Group 1, developed a calibration service to transfer the national standard for ^{60}Co absorbed-dose-to-water to the AAPM Accredited Dosimetry Calibration Laboratories (ADCLs), who in turn calibrate clinical instruments. Every two years, NIST conducts a round-robin comparison whereby NIST circulates a calibrated chamber for calibration at the four ADCLs. The calibration factors determined at each ADCL are compared to those determined by NIST to ensure consistency. The second round-robin comparison was performed this year. (J. Shobe)

Direct Determinations of Absorbed Dose to Water. Nearly a decade ago, the work of Steve Domen on the development of a sealed-water calorimeter culminated in the first direct determination of the absorbed dose at a point in water from ^{60}Co gamma-ray beams. This result has served as the NIST standard since then. NIST has had a second-generation version of the Domen calorimeter designed and constructed with more modern components and computer-based control and data acquisition. With the installation of our new, strong ^{60}Co teletherapy source, calorimetric measurements will be now again possible. For use with the new, stronger source, NIST received delivery of a new water calorimeter to perform the absorbed-dose-to-water measurements. The new calorimeter is based on the original Domen design, that serves as the national standard for absorbed dose, but with a number of improvements in construction and with computer-controlled automation and data acquisition. The calorimeter will be tested, refined and augmented as needed with the goal of establishing this instrument as the national standard for absorbed-dose-to-water. This will then make possible the use of the calorimeter in beams other than ^{60}Co (e.g., high-energy x-ray beams from accelerators, proton beams) for the direct calibration of dosimetry instruments used in therapy, and will facilitate a broader range of international comparisons. (J. Shobe)

Air-Kerma and Absorbed Dose Calibration of ^{192}Ir Brachytherapy Seeds. NIST calibration of ^{192}Ir seed sources was first introduced in 1980. Because of a half-life of only 74 days, it is impractical for NIST to maintain calibrated sources for subsequent calibration of instruments. Rather, measurement results are transferred to a reentrant ionization chamber that then serves as a secondary standard. In recent years, ^{192}Ir sources have become increasingly popular for use in the treatment of certain cancers, and new seed designs are being introduced. Manufacturers send such seeds to NIST for calibration, and those seeds are used to calibrate transfer chambers used by the manufacturer to characterize seeds for shipment and used by secondary calibration laboratories to further calibrate instruments used in therapy clinics. New ^{192}Ir seed sources are currently being calibrated in terms of both air-kerma and absorbed-dose-to-water. A comparison between the absolute calibration method of 1980 and newer methods have been performed. The calibration has been transferred to a NIST well-ionization chamber. Work is continuing to determine the absorbed dose from the new seeds. (J. Shobe, C.G. Soares, M.G. Mitch)

Calibration of Low-Energy Photon Brachytherapy Sources. Small radioactive seed sources used in prostate brachytherapy, containing either the radionuclide ^{103}Pd or ^{125}I, are calibrated in terms of air-kerma strength using the NIST Wide-Angle Free-Air Chamber (WAFAC) that serves as the national standard for this quantity. The WAFAC is an automated, free-air ionization chamber with a variable volume, allowing corrections to be made for passage of the beam through non-air-equivalent electrodes. Seeds of seventeen different designs from twelve manufacturers have been calibrated using the WAFAC. Quantitative information on the spectrum of emitted photons, obtained for a seed from each submitted batch using HPGe spectroscopy, is used for quality control and to refine correction factors needed for WAFAC measurements. On-site characterization at seed manufacturing plants for quality control, as well as at therapy clinics for treatment planning, relies on well-ionization chamber measurements. Following the primary-standard measurement of air-kerma strength, the responses of several well-ionization chambers to the various seed sources are determined. The ratio of well-chamber response to air-kerma strength yields a response factor for the well-ionization chamber for a given seed type. Such response factors enable well-ionization chambers to be employed at therapy clinics for verification of seed air-kerma strength, which is then used to calculate dose rates to ensure effective treatment planning. A new NIST ionization chamber, specifically designed to characterize prostate brachytherapy seeds more efficiently than commercially available chambers, is currently being tested. (P.J. Lamperti, M.G. Mitch, S.M. Seltzer, B.M. Coursey)

X-Ray Spectrometry of Prostate Brachytherapy Sources. To understand the relationship between well-ionization chamber response and WAFAC-based air-kerma strength for prostate brachytherapy seeds, x-ray emission spectra are measured with an HPGe detector. Pulse-height distributions from the spectrometer are unfolded to obtain the true photon spectra emitted from the seeds in the transaxial direction. ^{103}Pd seeds from all five manufacturers emit very similar photon spectra, while there are five distinct spectra emitted by ^{125}I seeds from eleven manufacturers. These differences in ^{125}I seed emission spectra are a result of fluorescence x-rays emitted by the radionuclide support material, either silver or palladium. The effect of these fluorescence x-rays is to lower the average energy of the emitted spectrum, resulting in a lower well-ionization chamber current relative to air-kerma strength because of the greater energy sensitivity of the well-chambers compared to that of the WAFAC. Knowledge of seed emission spectra allows separation of well-ionization chamber response effects due to spectral differences from those due to seed internal structure and self-absorption, and also allows the refinement of correction factors that must be applied to the WAFAC measurements. (M.G. Mitch, S.M. Seltzer, P.J. Lamperti)

Use of Radiochromic Film Dosimetry for Brachytherapy Source Characterization. The high-resolution capability coupled with the relative insensitivity of the radiochromic-dye film system suggested its use for characterizing the small, high-dose-rate sources used in brachytherapy. In 2000, studies with ^{192}Ir sources continued, and studies of high-activity ^{125}I sources were initiated. Films were irradiated in various geometries and read with a high-resolution scanning densitometry. In addition to planar irradiations, single layers of film are wrapped around a 6 mm diameter plastic cylinder in which a seed or wire is placed. Other cylinders, made with solid water or A150 tissue-equivalent plastic with radii of 2, 4, and 5 mm, were used as well. This geometry yields information on seed axial and transaxial uniformity, as well as dose rate at depths of 2, 3, 4 and 5 mm in tissue. (C.G. Soares, M.G. Mitch)

Intravascular Brachytherapy Source Dosimetry. The use of beta-particle-emitting brachytherapy sources for the prevention of restenosis (re-closing) of coronary blood vessels after angioplasty continues to be actively explored. NIST has taken an early and leading role in the calibration of the sources used for this therapy, employing the NIST extrapolation chamber equipped with a 1 mm diameter collecting electrode to measure dose rate at a depth of 2 mm in water-equivalent plastic. These measurements are confirmed using radiochromic-dye film, which is also used to characterize sources in the cylindrical geometry for transaxial uniformity. In addition, irradiation of planar sheets of film at various depths in water-equivalent plastic were used to construct data sets that can be used to predict the dose rate at arbitrary locations around the sources, using a modified form of the AAPM Task Group 43 Protocol. A publication describing this work has been published in the journal Medical Physics. The equipment used for these studies was augmented with the addition of an automated micro-scintillator detection system and various well-ionization chambers. Use of all this equipment has been centralized in a newly refurbished laboratory. Collaborations were continued with Guidant for dosimetry of a ^{32}P wire, with Novoste for dosimetry of ^{90}Sr/^{90}Y seed trains, with Washington Hospital Center for dosimetry of various sources, with Cordis for the dosimetry of ^{125}I wires, and with Best Industries for ^{188}W/^{188}Re wire and ^{192}Ir seed sources. A refinement was made to the NIST calibration procedure using the extrapolation chamber that resulted in a +15% change to the Novoste seed-train calibrations. This value now more closely agrees with the reference dose rates predicted by theoretical models and measured source activities. (C.G. Soares, M.G. Mitch)

LabVIEW Automation of Brachytherapy Dosimetry Measurements. Data acquisition and instrument control for all measurement stations in the NIST beta-brachytherapy laboratory (including well-ionization chambers, extrapolation chamber and plastic scintillator) are automated using LabVIEW (National Instruments), a graphical programming language. LabVIEW incorporates DataSocket technology, which allows live data transfer between computers over the Internet. This can be used in conjunction with a video teleconferencing link, providing a “virtual presence” at NIST for scientific collaborators and calibration customers. Data from instruments at NIST can be passed over the Internet to a collaborator's computer, also running LabVIEW, while communication between investigators (and observation of instrument function) is enabled through the use of video cameras and microphones. Such real-time interaction between NIST scientists and their industrial colleagues during a measurement will improve the overall efficiency of collaborative research. (M.G. Mitch, C.G. Soares)

Imaging-Plate Dosimetry. The imaging plate is approximately 0.5 mm thick composed of flexible plastic film coated with photo-stimulable phosphor powder (BaFX: Eu^{2+}, X = Cl, Br, I) in an organic binder, and is a sensitive two-dimensional detector of ionizing radiation. Following exposure, the plate is placed into a reader where its surface is scanned with a laser, releasing photo-stimulated luminescence, which is converted into a two-dimensional digital image. Phosphoimaging technology is currently used in applications such as radiography and the measurement of source activity distributions. Preliminary studies at NIST have suggested that the imaging plate can be successfully applied to dosimetry measurement problems involving low dose rates, on the order of 1 µGy/s, inaccessible by radiochromic film. Such a low-level dosimeter would be very useful, for example, in characterizing dose distributions from new, low-activity brachytherapy sources. (M.G. Mitch, C.G. Soares)

Modifications to the Mammography and 100-300 kVp X-Ray Calibration Ranges. A replacement Mo-anode x-ray tube was purchased and has been characterized for the NIST mammography proficiency testing and for routine calibrations. All NIST reference class chambers have been re-calibrated to the new, slightly different mammography beam qualities. The previous, repaired Mo-anode tube will be also be characterized and integrated into the calibration system. The data acquisition software upgrade is in the final testing stage and is being used to calibrate NIST reference chambers for proficiency testing. The tungsten x-ray calibration facility, which houses the primary standard for x rays between 100 kV and 300 kV has been completely redesigned. The x-ray facility is used to perform calibrations of ionization chambers to both NIST and ISO reference bremsstrahlung photon techniques. The recent upgrades allowed NIST to host an international primary-standard comparison. The modifications now permit quality-assurance comparisons between the NIST primary x-ray standards to be more easily conducted with improved reproducibility. The new design permits identical calibration techniques for all types of chambers, resulting in a lower uncertainty and maintaining high quality assurance. Moreover, the modifications will allow NIST to offer low-rate reference-beam-quality conditions, that can be used to better support low-level (environmental) dosimetry. The x-ray scatter conditions are much improved, and more ideally meet the requirements for the production of ISO beam qualities. The x-ray tube mount and shielding assembly was redesigned to include alignment features and a means of safe accessibility to the x-ray source for the required routine maintenance. The modifications included the rotation of the x-ray tube 90 degrees to use the longer and wider portion of the available space in the 300 kV calibration range. The range is now 2.5 times longer (over 5.7 m) than the previous range, and is now equipped with precision chamber-alignment mounts and support stand for the primary standard. General facility upgrades were also completed, including repairs to the ceiling, floor and walls for structural, shielding and aesthetic purposes. (C.M. O’Brien, J.H. Sparrow, P.J. Lamperti, M.R McClelland, R.Minniti)

X-Ray Comparison between NIST, NPL and NRCC for Low- and Medium-Energy Tungsten and Mammography Qualities. After a major renovation of the NIST conventional (W-anode) x-ray range, the x-ray facilities are available for calibrations and proficiency testing using 75 NIST and ISO beam qualities. Work was completed in time to host a direct comparison of national medium-energy x-ray standards with NPL (Britain), with the refurbished NIST range the only other national laboratory facility capable of accommodating the British standard. NIST hosted an international comparison of x-ray standards, which included a direct comparison between three US and two UK primary x-ray standards and an indirect comparison with two Canadian reference-class chambers. The standards were compared at energies ranging from 10 kVp to 300 kVp produced by tungsten and molybdenum x-ray anodes. The beam qualities used for the comparison included six narrow-spectra ISO beam qualities, two mammography qualities and 16 NIST beam qualities, including recently developed diagnostic beam qualities. The comparison between primary standards was conducted at NIST because the large size of the NPL 300-keV standard prohibits its use at the BIPM. The mammography standards were compared at the NIST because the BIPM does not maintain traceability to mammography beam qualities. The preliminary agreement for all energies shows agreement to better that 0.5%. (C.M. O'Brien, P.J Lamperti, J.H. Sparrow, M.R. McClelland)

NIST Mammography Proficiency Tests Performed to Ensure Transfer of Accurate Dose Calibrations. In an effort to meet the needs of calibration facilities that offer NIST traceable calibrations of air-kerma measuring instruments used in the mammography energy range, NIST provides proficiency testing. The FDA-MQSA "Final Rule for Quality Mammography Standards" requires that all clinical mammography units be calibrated with an instrument that is traceable to a national standard. A facility that provides the NIST traceable calibration must participate in a biennial proficiency program directly with NIST. The calibration facility must show a 3 percent agreement with the national standard in the mammography energy range. The proficiency test consists of a number of stages: First NIST calibrates a NIST transfer-quality ionization chamber, using two appropriate molybdenum- and/or rhodium-generated x-ray beam qualities. NIST then sends the transfer standard to the participating calibration facility, along with details of the NIST calibration conditions, excluding the calibration results. Calibrations of the NIST transfer chamber are made at the facility using the appropriate beam qualities. The NIST transfer chamber is returned to NIST, accompanied with the calibration results for each beam quality. Upon receipt of the chamber at NIST, it is re-calibrated to assure stability and proper working condition, and a proficiency report is issued. The goal of the proficiency test is to assure that the calibration facility is transferring quality calibrations under their routine conditions. The mammography calibration facility has been prepared for the continuation of NIST mammography proficiency testing. The characterization of the new Mo anode x-ray tube has completed the final stages with the verification of the standard correction factors. All NIST reference chambers to be used for NIST proficiency testing in mammography beams are currently being calibrated using the new Mo anode. The data-acquisition software upgrade is in the final testing stage. NIST recently notified six facilities of their successful completion of a mammography proficiency test. (C.M. O'Brien)

Improving Traceability of Dose Received in Mammograms around the World. Calibrations have been completed for the International Atomic Energy Agency (IAEA) using the NIST Mammography Calibration Facility. The NIST calibrations were performed for the IAEA Dosimetry and Medical Radiation Physics Section, who operate the central laboratory of the IAEA/WHO network of Secondary Standard Dosimetry Laboratories (SSDLs). The IAEA laboratory provides traceable calibrations, free of charge, to all SSDLs of the 76-member network. In addition, quality audit services (using TLD and ion chambers) are organized for SSDLs to help them verify their set-up and procedures. The NIST Mammography Facility was used to provide calibrations for each of the seventeen NIST mammography x-ray beam qualities; the IAEA laboratory modeled their available mammography beam qualities after the NIST facility. The IAEA will then transfer the NIST measurements of mammography x-ray beam air-kerma (exposure) throughout the IAEA/WHO network. The IAEA chamber was also calibrated at the German standards laboratory, the Physikalisch-Technische Bundesanstalt (PTB). The SSDLs will now be traceable to both PTB and NIST for the dose delivered in mammograms. In May NIST sent a reference class ionization chamber to the PTB for an indirect comparison with their primary standard for mammography. The agreement was better than 0.3%. This was the second indirect comparison between NIST and PTB in five years. Because the BIPM does not provide calibrations for mammography x-ray beams, NIST verifies agreement with other national standards laboratories through bilateral comparisons. (C.M. O'Brien)

Beta-Particle Emitting Ophthalmic Applicator Calibration Service. With the advent of the calibration service for ophthalmic applicators at the University of Wisconsin Accredited Dosimetry Calibration Laboratory, the routine role of NIST in these calibrations has diminished considerably. Two sources were calibrated in 2000. NIST's role in this field will henceforth be more geared towards providing transfer standard sources and fields both to secondary laboratories and source manufacturers. The results of the major international comparison of ophthalmic applicator dosimetry, which included the dosimetry of both curved and flat sources of $^{90}Sr+^{90}Y$ and $^{106}Ru+^{106}Rh$, were submitted to Medical Physics for publication in 2001 and are included in the ICRU report on beta particles for medical applications. LabVIEW code has been written and is now being used for the automation of the measurements within the framework of the NAMT automated source calibration facility. A new high-sensitivity electrometer has been purchased to allow measurement of lower activity sources with this system. (C.G. Soares, M.G. Mitch)

D. Protection and Accident Dosimetry

Gamma-Ray Ranges for Radiation-Protection Calibrations. Five gamma-ray sources are used for calibration of instruments and passive dosimeters, in terms of air-kerma and exposure, to support protection-level measurements in the US. The calibrations are directly traceable to measurements with the national primary standard for gamma-ray exposure, graphite-cavity ionization chambers. The ranges provide a wide range of air-kerma rates: two ^{137}Cs sources provide air-kerma rates from 4.5 mGy/h to 110 mGy/h; a third ^{137}Cs source provides air-kerma rates of 2.3 Gy/h and 3.6 Gy/h; and two ^{60}Co sources provide air-kerma rates from 0.25 mGy/h to 5.4 mGy/h. In addition, two ^{60}Co teletherapy-level sources are available. Programs of regular, calibrated exposures of thermoluminescent dosimeters provide direct support for the worker-protection measurement programs of a number of agencies, including the US Navy. NIST standards are also disseminated through a number of secondary instrument-calibration laboratories to provide traceability of protection-level measurements. Plans are underway to develop a calibration capability at much lower air-kerma rates, approaching those involved in environmental-level measurements. (R. Minniti, P.J. Lamperti, J. Shobe)

12th International Intercomparison of Environmental Dosimeters. The twelfth in a series of comparisons initiated in 1974 was conducted in collaboration with the U.S. Department of Energy. Close to 150 participants from over 30 countries worldwide submitted dosimeters for the testing. As there are currently no accreditation programs for environmental dosimetry, this is a means by which participants can compare their results with those of their peers. This comparison was held at Brookhaven National Laboratory in New York and was designed to test various aspects of the draft ANSI N13.29 standard that supplies criteria for the testing of environmental dosimeters. NIST provided proficiency testing of the U.S. DOE's quality control dosimeters as well as furnished ionization chambers for quality control purposes for the laboratory irradiations. NIST is also involved in the final data analysis and report write-up. (J. Shobe)

Calibration of Beta-Particle Sources and Instruments for Radiation Protection. A calibration service for protection-level beta-particle sources and instrumentation has been in place for several years. The measurement system is automated and capable of measuring extremely low absorbed-dose rates. The automation control software has been rewritten in LabVIEW code. In 2000, the system was used to calibrate five protection-level beta particle sources. The second-generation beta-particle secondary standard system (BSS2), that includes the isotope ^{85}Kr, is now utilized routinely for calibrations and research into standard extrapolation-chamber data-handling techniques. The sources were calibrated both at the Physikalisch Technische Bundesanstalt (PTB) and at NIST, allowing a direct comparison of calibrations. The systems are also being used for the dosimetry characterization of a photo-stimulatable luminescence phosphor imaging system. The standardized techniques developed at PTB and NIST are now included in an International Organization for Standardization draft standard and are being implemented in the NIST calibration service. A new high-sensitivity electrometer has been purchased to replace the 15-year old high-sensitivity electrometer currently being used for these measurements. (C.G. Soares, M.G. Mitch)

Validation of the EPR Method for Tooth-Enamel Dosimetry. Knowledge is required on dose effect relationships for radiation-induced stochastic and deterministic effects. Therefore, the acquisition of dosimetric data from populations with chronic exposure is of special interest (e.g., Chernobyl, Techa River, etc.). Electron Paramagnetic Resonance (EPR) is the only physical method available to retrospective biological dosimetry studies. Validation of the method and rigorous analysis of critical steps is essential before these data can be used reliably in epidemiological studies from which recommendations are made for occupational exposures. Significant effort has gone into developing sound protocols for the preparation of tooth tissue sample for EPR analysis, and into the analysis and interpretation of the EPR results. The long-term objectives of this work are to validate the EPR dose assessment methods for enamel and dentin. (A.A. Romanyukha, V. Nagy, M.F. Desrosiers)

Dose Response of the EPR Signal of Tooth Enamel. The dose saturation behavior for the tooth enamel EPR signal has been studied to determine the upper limit of the linear range. Accurate information on this controversial point was necessary for optimizing the additional-irradiation technique of dose reconstruction and to for check the hypothesis of a possible local signal saturation in enamel near the enamel-dentin interface (for dentin with a high beta-emitter concentration). The response was found to be linear to about 300 Gy. This means that it is safe to increase the additional doses to several Gy; this is highly desirable for increasing the accuracy of the reconstructed doses. This result, in combination with the data of Monte Carlo simulations, proved conclusively that local saturation of the signal in the enamel interface layer cannot occur. Thus, the accuracy of reconstructed doses from teeth with very high concentrations of Sr-90 in dentin (e.g., in the case of residents of Techa riverside) will not be adversely affected. (V. Nagy)

Tooth-Enamel Mass Corrections. To validate EPR tooth-enamel dose assessments, all aspects of the procedures are being analyzed and optimized. The first steps involve sample preparation, in which the enamel is isolated from the dentin, crushed and sieved. Because the enamel mass fraction varies from tooth to tooth, any comparisons must be corrected for this difference. However, due to the non-linearity of the microwave field in the EPR resonator, this correction is not straightforward. A critical parameter in this correction is the sample density; thus care must be taken to ensure that the sample is packed uniformly. For sample masses greater than 200 mg (that fill an EPR tube to more than 2 cm), a density normalization can be used. For masses below 100 mg, a careful normalization must be done. (O. Sleptchonok, V. Nagy, A.A. Romanyukha, M.F. Desrosiers)

Effects of Tooth Geometry on the Accuracy of Doses Reconstructed by EPR. A methodology based on Monte Carlo calculations has been developed to correct EPR-reconstructed doses for dose nonuniformity in enamel due to the limited penetration by $^{90}Sr/^{90}Y$ beta particles deposited internally in the dentin. The results obtained make it possible to accurately compare doses reconstructed from teeth of different sizes and/or geometries. They demonstrate that the dose to dentin is far less sensitive to the tooth size and shape than the corresponding dose to enamel. Consequently, dose reconstruction from internal emitters in dentin offers considerable advantages in terms of accuracy despite the poorer detection limit. Also, this methodology provides a means for relating enamel dose to the radionuclide concentration in dentin, a quantity that can be used in models aimed at determining doses to critical organs. (S.M. Seltzer, A.A. Romanyukha, V. Nagy)

Retrospective Dosimetry Measurements for the Semipalatinsk Study. A total of 459 nuclear explosions were conducted by the USSR between 1949 and 1989 at the Semipalatinsk nuclear test site. The National Cancer Institute is conducting a major study of the effects of radioactive fallout on the population (~500,000) of this region in the northern part of the Kazakhstan Republic. NIST is now working to provide dosimetric information for this study from EPR analysis of teeth from people in the region. (A.A. Romanyukha, M.F. Desrosiers)

Retrospective Dosimetry for the Techa River Study. The DOE is collaborating with NIST to conduct a focused EPR dosimetry study coupled with photo-stimulable phosphor imaging-plate characterization and ^{90}Sr analysis, on selected teeth from the Techa River population and others in the Southern Urals (for background data). The results of this study will significantly contribute to efforts to validate the dose estimates of Project 1.1 of the US-Russia Joint Coordinating Committee on Radiation Effects Research (JCCRER). The main areas of improvement will be focused on the development of non-destructive methods, lowering the cost of the dose assessment, and enhancing the quantitative aspects of the procedures. The main focus will be the application of the non-destructive image-plate method; employment of this method will lower cost and increase the throughput of the dose assessment while maintaining the quantitative aspects of the procedures. Dose validation through EPR measurement is considered to be critical to the success of the project. However, in the case of internal emitters, the applicability of the measured dose has been somewhat ambiguous. Our work will provide the bridge to make the EPR dose much more biologically relevant. Quantitative image-plate data coupled with EPR doses will enable the differentiation of internal and external dose contributions. This approach is the first step in the convergence of retrospective methods with real-time measurement methods (e.g., whole-body counting). This path will provide a credible basis for the derivation of radiogenic risk factors. (A.A. Romanyukha, V. Nagy, M.F. Desrosiers)

Strontium-90 Imaging of Dental Tissues. Tooth-enamel EPR dosimetry is able to reconstruct the total life-accumulated radiation dose to individuals. In the case of Techa riverside residents (near the Mayak nuclear weapon plant, Urals, Russia) who had permanent teeth during the exposure period, this total dose consists of two main components, a dose due to internal exposure from ^{90}Sr (accumulated mainly in the dentin) and a dose due to external exposure from Techa River radioactive pollution. Thus, in order to determine the external dose component, it is necessary to subtract the ^{90}Sr dose contribution from the total dose measured by EPR. The ^{90}Sr component of the tooth enamel dose can be determined from ^{90}Sr mapping of dental tissues with an image plate. To map ^{90}Sr in dental tissues the tooth will be vertically cross-sectioned into two approximately equal halves, and then the flat side of each tooth half is placed on the imaging plate for 3-40 h, depending on the level of ^{90}Sr deposition. In order to quantify the ^{90}Sr activity producing the dose distribution in the resulting image, a calibrated ^{90}Sr source will be constructed and prepared. The non-destructive assessment of activity can be used to estimate the absorbed dose from the internally deposited ^{90}Sr, and the tooth (both halves) can then be used to prepare the tooth-enamel sample for EPR dose-reconstruction measurements. (A.A. Romanyukha, V. Nagy, M.F. Desrosiers, M.G. Mitch)

Individual Biodosimetry at the Natural Radiation Background Level. Accurate knowledge of the dose from natural background radiation is a critical element in epidemiological studies of exposed populations. Until recently, there was no reliable method for direct measurement of individual doses at the background level. The assessment of individual doses and their variation within a population can be obtained directly by electron paramagnetic resonance (EPR) spectrometry of teeth. A specially designed experiment for the determination of the dose detection limit for EPR tooth dosimetry yielded a dose threshold of 29 mGy. NIST is working with the manufacturer of the EPR spectrometers to optimize the instrument design for sensitivity in the spectral region for the paramagnetic center corresponding to irradiated dentin samples. This breakthrough will enable dose-reconstruction studies for populations exposed at the natural background levels of ionizing radiation. (A.A. Romanyukha, V. Nagy, O. Sleptchonok, M.F. Desrosiers)

3. PUBLICATIONS

Berger, M.J. and Seltzer, S.M., *Database of Cross Sections for the Elastic Scattering of Electrons and Positrons by Atoms*, National Institute of Standards and Technology publication NISTIR 6573 (2000).

Böhm, J., Alberts, W.G., Swinth, K.L., Soares, C.G., McDonald, J.C., Thompson, I.M.G., and Kramer, H.-M., "ISO Recommended Reference Radiations for the Calibration and Proficiency Testing of Dosemeters and Dose-Rate Meters used in Radiation Protection", Radiat. Prot. Dosim. **86**(2), 87-105 (1999).

Boukharouba, N., Bateman, F.B., Brient, C.E., Carlson, A.D., Grimes, S.M., Haight, R.C., Massey, T.N., and Wasson, O.A., "Measurement of the n-p Elastic Scattering Angular Distribution at E_n = 10 MeV," in *Reactor Dosimetry: Radiation Metrology and Assessment*, ASTM STP 1398, edited by John G. Williams, David W. Vehar, Frank H. Ruddy, and David M. Gilliam, (ASTM, West Conshohocken, PA), pp. 431-438 (2001).

Burns, D.T., Lamperti, P.J., and O'Brien, C.M., "Comparison of the NIST BIPM Air-Kerma Standards for Measurements in the Low-Energy X-Ray Range," J. Res. Natl. Inst. Stand. Technol. **104**(2), 135-140 (1999).

Chappas, W.j., Deveny, B.G., Olding, R.P., and McLaughlin, W.L., "EB curing of maritime composite structures," Radiat. Phys. Chem. **56**, 417-427 (1999).

Desrosiers, M.F. Nagy, V.Yu. Sleptchonok, O.F. "Reply to letter to the editor by R.B. Hayes," Radiat. Phys. Chem. **59,** 445-4472 (2000).

Desrosiers, M.F., Nagy, V.Yu., Romanyukha, A.A., "Comment on Article by Haskell, Hayes, and Kenner," Health Physics **77,** 470-471 (1999).

Ebraheem, S, Beshir, W.B., Kovács, A., Wojnárovits, L., and McLaughlin, W.L., "A new spectrophotometric readout for the alanine-triphenyl tetrazolium chloride system for high-dose dosimetry," Radiat. Phys. Chem. **55**, 785-787 (1999).

Gesell, T.F., Hopewell, J.W., Lantz, M.W., Osborne, J.W., Scott, B.R., Seltzer, S.M., Shore, R.E. and Worgul, B.V., *Biological Effects and Exposure Limits for "Hot Particles,"* Report 130 of the National Council on Radiation Protection and Measurements (1999).

Hubbell, J.H., "Review of Photon Interaction Cross Section Data in the Medical and Biological Context," Physics in Med. & Biol. **44**(1), R1-R22 (1999).

Hubbell, J.H., "Compilation of Photon Cross-Sections: Some Historical Remarks and Current Status," X-Ray Spectrom. **28**, 215-223 (1999).

Hubbell, J.H., *An Examination of Available Incoherent Scattering S-Matrix Theory, also Compton Profile Information, and Their Impact on Photon Attenuation Coefficient Compilations,* National Institute of Standards and Technology publication NISTIR 6358 (1999).

Hubbell, J.H., "X-ray cross sections and crossroads (The International Radiation Physics Society) – Richard Pratt's contributions to both," Radiat. Phys. Chem. **59**, 113-125 (2000).

Klemic, J., Shobe, J., Miller, K., Shebell, P., Carolan, P.T., Holeman, G., Kahnhauser, H., Sengupta, S., Soares, C.G., and Assi, N., "State of the Art of Environmental Dosimetry: 11th International Intercomparison and Proposed Performance Tests," Radiat. Prot. Dos. **85**, 201-206 (1999).

Klemic, G., Shobe., J., Sengupta., S., "Environmental Dosimetry Performance Criteria: Pilot Test Of ANSI Draft N13.29," Health Phys. **78,** 370-376 (2000).

Kovács, A., Baranyai, M., Wojnárovits, L., Moussa, A., Othman, I., and Mclaughlin, W.L., "Radiolytic reactions of nitro blue tetrazolium under oxidative and reductive conditions: a pulse radiolysis study," Radiat. Phys. Chem. **55**, 795-798 (1999).

Kovács, A., Baranyai, M., Wojnárovits, L., Moussa, A., Othman, I., and Mclaughlin, W.L., "Aqueous-ethanol nitro blue tetrazolium solutions for high dose dosimetry," Radiat. Phys. Chem. **55**, 799-803 (1999).

Kovács, A., Baranyai, M., Wojnárovits, L., Mclaughlin, W. L., Miller, S. D., Miller, A., Fuochi, P.G., Lavalle, M., and Slezsák, I., "Application of the Sunna dosimeter film in gamma and electron beam processing," Radiat. Phys. Chem. **57**, 691-695 (2000).

Kovács, A., Baranyai, M., Wojnárovits, L., Slezsák, I., McLaughlin, W.L., Miller, A., and Moussa, A., "Dose determination with nitro blue tetrazolium containing radiochromic dye films by measuring absorbed and reflected light," Radiat. Phys. Chem. **57**, 711-716 (2000).

McLaughlin, W.L., Miller, S.D., Saylor, M.C., Kovács, A., and Wojnárovits. L. "A preliminary communication on an inexpensive mass-produced high-dose polymeric dosimeter based on optically-stimulated luminescence," Radiat. Phys. Chem. **55**, 247-253 (1999).

McLaughlin, W.L., Silverman, J., Al-Sheikhly, M., Chappas, W.J., Liu Zhan-Jun, Miller, A. and Batsberg-Pedersen, W., "High-density polyethylene dosimetry by transvinylene FTIR analysis," Radiat. Phys. Chem. **56**, 503-508 (1999).

McLaughlin, W.L., Puhl, J.M., Kovács, A., Baranyai, M., Slezsák, I., Saylor, M.C., Saylor, S.A., Miller, S.D., and Murphy, M., "Sunna dosimeter: An integrating photoluminescent film and reader system; work in progress," Radiat. Phys. Chem., **55**, 767-771 (1999)

McLaughlin, W.L., Ebraheem, S., Beshir, W.B., Kovács, A., and Wojánrovits, L., "A New Spectrophotometric Readout for the Alanine-Triphenyl Tetrazolium Chloride System for High-Dose Dosimetry," Radiat. Phys. Chem., **55**, 785-787 (1999).

McLaughlin, W.L., and Kovács, A., "Radiolytic Reactions of Nitro Blue Tetrazolium Under Oxidative and Reductive Conditions: A Pulse Radiolysis Study," Radiat. Phys. Chem., **55** 795-798 (1999).

McLaughlin, W.L., "Reference Dosimetry and Calibrations with X an Gamma Rays and Electron Beams," *Dosimetry for Radiation Processing*, Proceedings of IAEA Meeting on Characterization and Evaluation of High Dose Dosimetry for Quality Assurance in Radiation Processing, *IAEA-TECDOC-1156*, International Atomic Energy Agency, Vienna, Austria, 125-129 (2000).

Mitch, M.G., Zimmerman, B.E., Lamperti, P.J., Seltzer, S.M. and Coursey, B.M., "Well-Ionization Chamber Response Relative to NIST Air-Kerma Strength Standard for Prostate Therapy Seed," Med. Phys. **27**, 2209-2214 (2000).

Mitch, M.G., Zimmerman, B.E., Lamperti, P.J., Seltzer, S.M. and Coursey, B.M., "Well-ionization Chamber Response Relative to NIST Air-kerma Strength Standard for Prostate Brachytherapy Seeds," Med. Phys. **27**, 2293-2296 (2000).

Mourtada, F.A., Soares, C.G., Seltzer, S.M. and Lott, S.H., "Dosimetry Characterization of a ^{32}P Catheter-Based Vascular Brachytherapy Source Wire," Med. Phys. **27**, 1770-1776 (2000).

Nagy, V.Yu, Puhl, J.M., Desrosiers, M.F., "Advancements in Accuracy of the Alanine Dosimetry System. Part 2: The Influence of the Irradiation Temperature," Radiat. Phys. Chem. **57**, 1-9 (2000).

Nagy, V.Yu., Sleptchonok, O.F., Desrosiers, M.F., Weber, R.T., Heiss, A.H. "Advancements in Accuracy of the Alanine Dosimetry System. Part 3: Usefulness of an Adjacent Reference Sample," Radiat. Phys. Chem. **59,** 429-441 (2000).

Nath, R., Amols, H.I., Coffey, C., Duggan, D., Jani, S., Li, Z., Schell, M., Soares, C.G., Whiting, J., Cole, R.E., Crocker, I., and Schwartz, R., "Intravascular brachytherapy physics: report of the AAPM Radiation Therapy Committee Task Group No. 60," Med. Phys. **26**, 119-152 (1999).

O'Brien, C.M., Lamperti, P.M., Williams, T., and Sander, T., "Comparison of the NIST and NPL Air Kerma Standards Used for X-ray Measurements Between 10 kV and 80 kV," J. Res. Natl. Inst. Stand. Technol **105**(5), 701-707 (2000).

Romanyukha, A.A.,, Nagy, V., Sleptchonok, O., Desrosiers, M., Jiang, J., and Hiess, A., "Individual biodosimetry at the natural radiation background level," Health Phys. **80**, 71-73 (2001).

Romanyukha, A.A., Seltzer, S.M., Desrosiers, M.L., Ignatiev, E.A., Ivanov, D.V., Bayankin, S., Degteva, Eichmiller, M.O., Wieser, A. and Jacob, P., "Correction factors in EPR dose reconstruction for the residents of the Middle and Lower Techa riverside." Health Phys. (in press).

Seltzer, S.M., Inokuti, M., Paul, H. and Bichsel, H., "Response to the Commentary by J. F. Ziegler," Letter to the Editor, Radiat. Res. **155**, 378-381 (2001).

Seltzer, S.M., Romanyukha, A.A. and Nagy, V., "Monte Carlo Calculations of the Dose Distribution in Teeth due to Internal Exposure from ^{90}Sr: Application to EPR Tooth Dosimetry," Radiat. Prot. Dosim. **93**(3), 245-260 (2001).

Shobe, J., Rodgers, J.E., and Taylor, P.L., "Scattered Fractions of Dose from 10, 18, and 25 MV Linear Accelerator X-Rays in Radiotherapy Facilities," Health Phys. **76**, 27-35 (1999).

Shobe, J., Klemic., G., "The U.S. Approach to Environmental Radiation Monitoring," Radiat. Prot. Dosim., **92**, 115-121 (2000).

Shortt, K., Shobe, J., Domen, S., "Comparison of Dosimetry Calibration Services at the NRCC and the NIST," Med. Phys., **27**(7), 1644-1654 (2000).

Sleptchonok, O.F., Nagy, V.Yu., Desrosiers, M.F., "Advancements in Accuracy of the Alanine Dosimetry System. Part 1: The Effects of Environmental Humidity," Radiat. Phys. Chem. **57,** 115-133 (2000).

Tayler, P.L., Rodgers, J.E., and Shobe, J. "Scatter Fractions From Linear Accelerators With X-Ray Energies From 6 MV To 24 MV," Med. Phys. **26**, 1442-1446 (1999).

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