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, for the meeting of Section I (X and γ rays, electrons) of the Consultative Committee on Ionizing Radiation (CCRI), May 18-20, 2005, Paris. The material was taken from information gathered for NIST program reviews, and covers roughly calendar years 2003 and 2004. Our technical activities are summarized in Section 2, identifying staff members involved in each project; Section 3 lists the Group's publications for the period.

2. Technical Activities

A. Theoretical Dosimetry and Quantum Metrology

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. The quality of the work of the Data Center is reflected in the many requests for our data from other laboratories and in the use of our data in engineering and scientific compendia, books and review articles, and in the reports and protocols of national and international standards organizations. The compilations of the Data Center rely heavily on the synthesis of available theory to extend the data and provide for comprehensive coverage over broad ranges of energy and materials. Thus we have long been involved in complex computational analyses and in the development of highly sophisticated transport-theoretic methods. Our Monte Carlo transport calculations also are incorporated into some of the most widely used general-purpose radiation transport codes. With the help of the NIST Physics Laboratory's Office of Electronic Commerce of Scientific and Engineering Data, a number of the Center's databases can be accessed on the worldwide web. (S.M. Seltzer, P.M. Bergstrom, J.H. Hubbell, M.J. Berger)

Cross Sections for the Elastic Scattering of Electrons and Positrons by Atoms. An evaluation of cross sections for the elastic scattering of electrons and positrons by neutral atoms has been done 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. 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. This work has greatly contributed to the efforts of a report committee on the elastic scattering of electrons and positrons, sponsored by the International Commission on Radiation Units and Measurements (ICRU), efforts which refine and improve results mainly for low kinetic energies. (M.J. Berger, S.M. Seltzer)

New Evaluations of the Compton Cross Section for Photon Interaction with Atoms. This year saw the completion of computations directed toward creating a new NIST database for inelastic photon-atom scattering. This database provides total cross section and subshell ratios for the ionization or Compton component of inelastic photon-atom scattering. Additionally, mass-energy absorption and mass-energy transfer coefficients are provided. These data are provided for all elements with nuclear charge Z from 1 to 92 and for energies from 1 keV to 20 MeV, the region where this process is most significant in the attenuation of photons. The computations were performed in the relativistic impulse approximation, which provides the cross section doubly differential in scattered photon energy and angle on a subshell-by-subshell basis. This cross section was computed using Dirac-Fock momentum distributions for the individual subshells. These results were then numerically integrated over energy and angle to obtain the totals. In the case of the mass-energy absorption and energy-transfer coefficients, additional data was required relating to emission of relaxation photons and bremsstrahlung radiation by ejected electrons. These data were taken from the Lawrence Livermore National Laboratory Evaluated Atomic Data Library and the NIST database corresponding to ICRU Report 37. (P.M. Bergstrom)

Review of Information on the Elastic Scattering of Photons. Periodically the Photon and Charged-Particle Data Center reviews progress on the development of radiation-interaction data to assess the need for new or updated standard-reference databases. Such a review is being carried out of the available theoretical and measured data on elastic (Rayliegh or coherent) scattering of photons. The focus is on recent advances that could improve the accuracy of photon-interaction data tabulations by NIST and others, and includes a quantitative assessment of the impact of new data, particularly from S-matrix calculations, on possible new NIST compilations of photon attenuation coefficients. (J.H. Hubbell)

Monte Carlo Transport and Applications. The Group has installed the major Monte Carlo codes for the transport of photons and electrons on our computational resources. We modify these codes and apply them to problems of interest in computational dosimetry and in imaging. A particularly important application has been highlighted in our response to recent bio-terrorism: anthrax in mail. Considerable effort has been dedicated to the theoretical dosimetry for industrial mail irradiations by electron and bremsstrahlung beams. The results of this modeling informed our experimental approach and aided in timely advice to the US Postal Service and their contract irradiation facilities on radiation-processing parameters to effectively decontaminate the mail and parcels, while minimizing effects due to overdosing. A program of Monte Carlo calculations was conducted to support a feasibility study on the irradiation of high-risk passenger luggage to reduce the risk from smuggling of bioterrorism agents for the Technical Support Working Group (TSWG), on behalf of the Department of Agriculture's Animal and Plant Health Inspection Service. This study coupled measurements and Monte Carlo calculations to develop accurate estimates of the radiation dose and the effects to a wide range of luggage/contents configurations. The Monte Carlo code PENELOPE was modified to support NASA in analyzing x-ray data obtained by the NEAR-Shoemaker mission. This mission was the first rendezvous of a spacecraft with an asteroid, 433 Eros. The x-ray spectrometer employed measured emission from the asteroid in the field of the incident solar radiation. Of particular interest in this study was the fluorescence radiation, which can be used to determine the composition of the surface of the asteroid, used here to investigate particle size effects on the x rays emitted from the surface. (P.M. Bergstrom, S.M. Seltzer)

Quantum Metrology. In mid-year the group has adopted a program of x-ray spectroscopy of exotic x-ray sources that was previously located in the Atomic Physics Division. Emphasis is placed upon optical design, instrument making, and novel calibration strategies. This includes the following FY04 collaborations: [1] The curved-crystal spectrometer (and CCD detector) at the U. of Debrecen's (Hungary) Electron Cyclotron Resonance (ECR) ion source spectrometer was calibrated in NIST's Advanced Measurement Laboratory this summer. Previous joint NIST/Debrecen imaging investigations have shown that highly charged ions are present in ECR sources at positions of local high electron density. High-spectral-resolution experiments are now planned to determine ion charge-state distributions inside the plasma. This will be compared to extracted-beam charge-state distributions to better understand the operation and physics of ion-beam extraction with ECR sources. [2] Ongoing crystal-spectroscopy efforts at the NIST EBIT with U. of Melbourne, Australia, generate data relevant to astrophysical and magnetically confined fusion applications. With high-resolution and absolute energy calibration, spectra are also used to test the latest atomic structure calculations. For the month of March we measured the resonance spectra from Ti_20^+ ions as a part of a systematic study of two-electron systems along the first row of transition elements on the periodic chart. [3] Collaboration with Titan Corporation's Pulsed Sciences Division involves the study nuclear weapon's effects and testing (NWET) related to transmission cables, and uses a reflex triode x-ray source called PITHON. This year we provided mounted bent crystals and the optical design for a transmission spectrometer used to characterize for the first time the spectral output of PITHON. We also used the free-air-chamber x-ray calibration facilities of the Group to achieve a sensitivity calibration for this novel instrument. [4] We have provided high-quality diffraction crystals, using the world's most perfect silicon, for a new vacuum double crystal spectrometer that is being constructed at Université Pierre et Marie Curie, Paris. Together with the NIST analog spectrometer, x-ray wavelength measurements tied to the definition of the meter will complement our recent wavelength-tables project. [5] Maintaining the institutional infrastructure to cut, align, and analyze crystal optics, and to produce and image x-rays, a low-energy (1 keV to 30 keV) x-ray calibration facility was upgraded with custom electron guns and anodes. Three labs were moved to NIST's new Advanced Measurement Laboratory (AML). [6] We are providing a multi-channel x-ray spectrometer diagnostic to the National Ignition Facility (NIF); it was upgraded in FY04, with among other things x-ray collimators and will be calibrated in FY05. This is a cluster of four reflection-geometry curved-crystal spectrometers and one transmission bent crystal instrument. [7] For the Bechtel Corporation, we have provided detailed instrument specifications and calibration strategy for a recently procured HPGe detector. This is to be used to calibrate x-ray diagnostics for NIF from 1 to 100 keV, and NIST has been requested to provide the absolute sensitivity calibration and protocols. [8] The group continues to produce custom-made electronic autocollimators for customers inside NIST and outside the United States. These are typically used with optical polygons and a method of circle closure developed by the group to calibrate goniometers used to measure diffraction angles (and therefore x-ray wavelengths) to better than a part per million. This fiscal year, units were produced for the NIST Ceramics Division and the Bede Corporation in Colorado. A contract has been received to provide similar units to the Institut Max Von Laue – Paul Langevin in Grenoble, France. (L.T. Hudson)

B. INDUSTRIAL DOSIMETRY

Internet-Based Calibration Services. Several years ago, NIST set out to create a system for fast remote certification of high-dose radiation sources against the U.S. national standard gamma-radiation source using the Internet. The Internet-based system promised to deliver immediate certification results to the industry customer on-demand at a lower cost. In earlier work, NIST successfully demonstrated a prototype of this service with modern technologies and commercially available products. NIST's high-quality alanine-EPR measurement system was coupled with the connectivity of the Internet to perform services remotely in real time. However, though the basic functions of this service worked, new developments made it clear that design revisions would be necessary. These changes were primarily driven by new information technology policies, especially those regarding security. Since systems security relies heavily on computer technology, new policies were enacted that dictated the manner in which computers could be connected to Federal government computer networks. The original design for the Internet-based transfer certification service required a constant uninterrupted connection between the company's computer and the NIST server throughout the entire measurement session. This requirement came in conflict with rules against such connections. Although it may have been possible to develop a solution to this conflict; other issues with the service design soon became evident. Connectivity on the industry end of the service communication link would not be guaranteed to be compatible with the service. The Internet connections for some company sites are limited to dial-up modems. Some company sites do not have the high-speed connection required by the service. It was also apparent that the rigid design of this service would effectively eliminate foreign subscribers. Open high-speed connections would be even more difficult to enable and maintain if the facility was outside the United States; moreover, the cost of this live connection to a foreign subscriber would likely be prohibitive. This next-generation Internet based dose certification service is a vast improvement over the rudimentary system demonstrated three years ago. Its revamped security features are compatible with computer security policies currently in use. The new communication mechanisms (encryption versus open connections) are based on standard practices that should enable it to be adaptable to any future changes in security policies. The next-generation service is also more compatible with industry systems capabilities and offers full accessibility to foreign subscribers. Multiple levels of state-of-the-art encryption technology ensure the protection of private information as well as the highest degree data integrity. A working beta version of the new service is expected early in the next fiscal year. (M.F. Desrosiers, J.M. Puhl)

Low-Temperature Irradiation Effects on Alanine Dosimeters. Early researchers in alanine dosimetry established that, at least in the 0 ºC to 50 ºC temperature range, the amplitude of the electron paramagnetic resonance (EPR) signal of irradiated alanine grows linearly with irradiation temperature. The irradiation temperature coefficient is derived from the slope of this response-irradiation temperature relationship. However, very little data exists on the linearity of the response below 0 ºC. Thus, the applicability of the irradiation temperature coefficient determined above 0 ºC to irradiations conducted below 0 ºC is uncertain. This work investigates the behavior of the alanine response irradiated using a ^{60}Co gamma source over the temperature range -77 ºC to +50 ºC. As the temperature coefficient is known to be dose dependent, a series of dose response studies were conducted over a dose range of 0.5 to 100 kGy. The temperature rise in materials treated with high-rate industrial ionizing radiation sources is an important influence factor on the dosimeters used to model or monitor the irradiation process. For alanine dosimeters, the temperature during industrial irradiation processing affects the radical production that is reflected in the measured response of the dosimeter. The relationship between the dosimeter's radiation response to absorbed dose and its temperature during irradiation is termed its irradiation temperature coefficient. This temperature coefficient is typically expressed in percent change per degree, and for L-alanine is slightly above +0.1 %/ºC for temperatures above zero Celsius. In many industrial applications, processing typically occurs at ambient temperatures, and dosimeters are characterized under the conditions of use. The advent of food irradiation expanded the range of interest to sub-zero temperatures and extended the range over which the coefficient was characterized to approximately -10 ºC. Recently, an ever-growing number of products are being irradiated that require temperature control at even lower temperatures (*e.g.*, sera used in cell cultures and tissue for implantation), and these applications have fueled the need for investigating the behavior of dosimeters at much lower temperatures. A key step in launching new irradiation applications at low temperature will be regulatory approval of the process. This requires measurements of absorbed dose made by the industrial processor to be accurate and traceable to a national metrology institute (NMI). As alanine is the reference dosimetry system used by all NMIs in their high-dose calibration services, a characterization of the alanine low temperature dose response was undertaken. Extension of the temperature range to -77 ºC revealed a dosimeter response that is lower than that predicted from the linear relationship above -10 ºC. The deviation from linearity increased with decreasing temperature and was observed for both commercial dosimeters. The implications for dosimetry are that linear temperature corrections can only be applied in the -10 ºC to +50 ºC irradiation temperature range. A non-linear correction must be applied below -10 ºC. For the NIST measurements between 0.5 kGy and 50 kGy, a third-order polynomial would be suggested to apply response corrections. However, it has yet to be determined if this correction is dosimeter-batch specific. These data also suggest that, depending on the precision requirements of the dosimetry system employed, a single relationship for this correction can be applied below 50 kGy. However, it is likely that corrections related to absorbed dose should be used above 50 kGy. (M.F. Desrosiers, S.L. Cooper, J.M. Puhl)

Irradiation Temperature Coefficient for L-Alanine and DL-Alanine Dosimeters. Correcting for the average temperature experienced by a dosimeter during irradiation with electrons and photons improves the accuracy of the dose measurement. The relationship between the dosimeter's radiation response to the absorbed dose and its temperature during irradiation is termed the irradiation temperature coefficient. This temperature coefficient is typically expressed in percent change per degree. The temperature rise in dosimeters irradiated with high-intensity ionizing radiation sources can be appreciable; however, the temperature during irradiation is often difficult or impractical to be measured directly. In the absence of a direct measurement, an estimation of the irradiation temperature is often employed to make this correction for the computation of absorbed dose. Since this estimate includes unavoidable significant errors, the magnitude of the temperature coefficient is the next consideration in any efforts to minimize the measurement uncertainty. The differences in published temperature coefficients are attributed to several factors that include: the polymer binder type and concentration; manufacturing parameters; experimental design of the temperature-controlled irradiations; and, computations from limited data. One influence not explored was the isomeric composition of the alanine. Alanine is commonly sold in two forms, as L-α-alanine, composed solely of the L isomer, and as DL-α-alanine, a mixture of the L and D isomeric forms. To address this issue NIST collaborated with the Radiometrology Center of the China Institute of Atomic Energy (Drs. Min Lin, Ying Cui, and Kesheng Chen). The CIAE manufactured the dosimeters that were irradiated with NIST high-precision temperature-controlled irradiation apparatus. The DL-alanine temperature coefficient was measured as 0.24 %/K, is 57 % higher than the L-alanine temperature coefficient, 0.15 %/K. This study determined conclusively that the temperature coefficient for the dosimeters prepared with DL-alanine is >50 % higher than those prepared with L-alanine dosimeters. Therefore, L-alanine dosimeters are preferred for measurement applications where the irradiation temperatures cannot be accurately measured and/or differ greatly from the calibration irradiation temperature, especially if minimizing the measurement uncertainty is a concern. (M.F. Desrosiers, S.L. Cooper)

Alanine-Dosimetry-Technology Transfer to Industry. In calibration laboratories, the relative humidity (RH) is either controlled or very limited in range. However, the range of environments those dosimeters are exposed to can vary widely from one geographic region to another. Preferably, a dosimeter should either be insensitive to its environment or respond in a predictable manner to environmental influences ensuring consistent and comparable results between facilities in different locations. Post-irradiation stability, sometimes referred to as "fade characteristic" is also an important attribute. If the post-irradiation response of the dosimeter changes significantly over time, the time-dependant dosimeter measurements require additional controls to ensure readings are taken at the correct interval. This lack of flexibility can have detrimental effects to facility scheduling where necessary shutdowns for maintenance or source replenishment may make delays in analysis unavoidable. NIST collaborated with STERIS, an industrial irradiation processor, Bruker, the dosimetry system reader manufacturer, and Kodak, the dosimeter manufacturer, to examine the utility of alanine dosimetry in an industrial environment. These tests were performed on the Kodak alanine dosimeter film. Several groups of these alanine dosimeters were conditioned at NIST in relative humidity environmental chambers controlled to 0 %, 33 %, 44 %, 57 %, 75 % and 94 % RH. After the dosimeters were conditioned for several days, they were hermetically sealed in sachets. After setting aside conditioned dosimeters for gamma irradiation at NIST, several sachets of dosimeters equilibrated at 0 %, 33 %, 75 %, and 94 % RH were shipped to STERIS Isomedix for gamma-ray and electron-beam irradiation and post-irradiation analysis. From this experiment it was concluded that the response of the Kodak alanine film dosimeters is relatively insensitive to the effects of humidity over a broad range of RH. While the existing industry standard calls for packaging to protect the dosimeter from the effects of the humidity in the environment, these data suggest that this requirement is unnecessary for the Kodak alanine dosimeter, although packaging may be advisable if the possibility of damage exists during dosimeter handling in the industrial process. During the time-dependence measurements, all dosimeters were stored in a controlled environment with a temperature in the range of 15.0 to 25.0 °C. Maintaining these dosimeters in a controlled environment for this experiment indicates that the Kodak alanine film dosimeters are subject to little if any fade or development characteristics. The alanine dosimetry system has long been heralded as superior to all other dosimetry systems used in industrial processing. However, because the alanine system use has been limited to primary and secondary calibration laboratories, the transferability of this system to the potentially harsh conditions at the industrial level was unclear. The interoperability between gamma and electron-beam irradiated dosimeters is important to establishing traceability to national standards. These data demonstrate that the superior attributes of the alanine system are transferable to industry. (M.F. Desrosiers, S.L. Cooper)

Barium Dithionate as an EPR Dosimeter. The amino acid alanine dosimetry system's recent transition from a reference-class dosimeter to a routine dosimeter has stimulated several new areas of research. Electron paramagnetic resonance (EPR) studies of irradiated solid alkaline-earth metals (Me) dithionates, $MeS_2O_6 \times H_2O$ have shown they possess good properties as sensors for dosimetry. Studies of gamma-irradiated barium dithionate ($BaS_2O_6 \times 2H_2O$) revealed a narrow and approximately isotropic EPR signal with g-factor of 2.0036 and a linewidth (ΔHpp) of 0.55 mT. The radical ion SO_3^- has been proposed as a model for the radiation-induced paramagnetic center. Weak additional satellite EPR signals with splitting of 11.5 mT were observed and attributed to the hyperfine isotropic splitting due to ^{33}S isotopes. The main advantage of dithionates in dosimetry is the comparatively narrow EPR signal. As a dosimeter, $BaS_2O_6 \times 2H2O$ was found to be usable up to 5×10^4 Gy with an uncertainty of 6 %. The system's long-term stability is exceptional in that the EPR signal amplitude was stable (within 5 %) for at least two years. Recent work includes comparisons to alanine, irradiation temperature effects, and minimum detectable dose. The radiation yield of barium dithionate is 8×10^{13} spin/(g Gy); the radiation yield (G-value) for alanine is 2.5×10^{14} spin/(g Gy). The temperature coefficient was estimated to be 0.10 %/K. The low-dose threshold using the ISO 11843 method is 9 mGy. (M.F. Desrosiers)

New High-Dose Dosimetry Systems. Dosimeters containing three separate radiation-sensitive materials, alanine, sugar, and ammonium tartrate, were supplied by Dr. Yordanov of Bulgaria. The three dosimeter types were cylinders 4 mm in diameter and 12 mm long. The detector material was bound by paraffin. Each dosimeter contained the radiation-insensitive paramagnetic ion, Mn(II), intended to serve as an EPR intensity reference material. According to Dr. Yordanov, the alanine response to Mn ratio should be a constant after normalizing to dose such that one could use this ratio to obtain the absorbed dose in the absence of a calibration curve. Both signals are recorded in the same spectral scan. The concentration of the Mn reference material was set for use in the 1 to 25 kGy range. The response ratio is determined by irradiating a single dosimeter to one or more doses in the 1−3 kGy range. The response ratio is determined at each dose level and the mean of these measurements is used for dose estimates from dosimeters for that specific batch. Uncertainty tables were compiled for the Alanine/Mn system. An expanded uncertainty of 10.9 % was computed. A similar calculation for the sugar and tartrate systems yielded expanded uncertainties of 6.2 % and 5.3 %, respectively. The concept of incorporating the reference material in the dosimeter is reasonable; perhaps manufacturing issues contribute to the measurement problems observed here. A dosimeter fragmentation experiment demonstrated inconsistencies in dosimeter composition. The large overlap of the broad alanine signal with the narrow Mn signal strongly contributes to the measurement problems. The sugar spectrum is narrower than alanine but suffers measurement issues because of its complicated spectrum. The tartrate system has a simpler and narrower EPR spectrum that contributes to its better performance. The uncertainties reported here are crude estimates. Improvements of 2−5 % could be expected with more testing. (M.F. Desrosiers)

Improvements to Accelerator Facilities. The Radiation Interactions and Dosimetry Group continues to support research efforts in industrial and medical dosimetry and radiation hardness and materials effects studies. In the past year our electron accelerator facilities were used in a wide variety of dosimetry and fundamental physics studies, as well as in applied research in homeland security and materials modification. This work includes the irradiation of cryogenic samples for nuclear polarization studies and biomedical applications, benchmark shielding measurements for Monte Carlo computer modeling, and radiation hardness measurements of MOSFET semiconductor devices. In addition, the beam line for the Division’s High Energy Computed Tomography (HECT) facility has now been constructed, and we have begun a series of beam emittance studies to characterize this beam line. We are constantly seeking to upgrade and expand our capabilities. This past year saw the installation and acceptance testing of a Clinac 2100C medical accelerator. This accelerator will form the basis of a medical dosimetry research facility providing high-quality electron and photon beams representative of those used in the clinical setting. NIST personnel have begun a set of measurements to characterize the performance, reliability, and dose output of the accelerator. After this initial testing phase, the facility will be used in the development of high-energy medical dosimetry standards, including a second-generation Domen-type water calorimeter. Our future goals include the establishment of a primary calibration laboratory for high-energy medical dosimetry based on this accelerator. (F.B. Bateman, M.R. McClelland)

C. Medical Dosimetry

Water Calorimetry. A decade ago, Steve Domen developed a sealed-water calorimeter at NIST that was used to make the first determination of the absorbed dose at a point in water from ^{60}Co gamma-ray beams. This result has served as the NIST standard, and has been disseminated through the Accredited Dosimetry Calibration Laboratories (ADCLs) to the medical physics community. Since then, the adoption by the medical physics community of dosimetry protocols based on absorbed dose to water, rather than air kerma, has driven the development of a second-generation Domen calorimeter. Modeled on the original sensors and bridge architecture, the new design incorporates ac excitation and phase-sensitive detection electronics operating under computer control. The device, like similar devices in operation at standards labs throughout the world, is nevertheless susceptible to noise due to convection and conduction of heat within the water medium. In the process of evaluating options such as refrigeration and stirring systems that have proved successful elsewhere for dealing with convection and conduction noise, we have arrived at a new approach to the problem: frequency-domain analysis techniques for isolating the signal of interest. Initial findings suggest that it is able to reproduce the results of traditional, time-domain analysis techniques but at much higher precision. Should this analysis prove to be sufficiently accurate, it may be possible to avoid the more cumbersome refrigeration/stirring interventions in use elsewhere, and thereby have a simpler, more portable primary standard instrument. Tests are being conducted with the newer ^{60}Co source and will be conducted with the original ^{60}Co source used by Domen, in order to establish consistency with the earlier standard. More recently, the calorimeter has been tested with the new Varian 2100C CLINAC with the goal of extending its use to high-energy photon and electron beams, with eventual calibration services in these areas. Frequency-domain techniques may prove to be especially useful here, where accelerator-related instabilities further hinder extraction of radiation-induced heating signals. A second line of calorimetry research, initiated recently with the award of an SBIR grant to Luna Technologies (Hampton, VA), will evaluate ultrasonic techniques for measuring radiation-induced temperature changes in water, which may thereby result in a new type of water calorimeter. Pending the success of the Phase II funding, within the first half of 2005, the Group expects to receive a research prototype ultrasonic sensor system that uses pulsed phase-locked loop (PPLL) technology to derive temperature measurements in a water phantom with better than 10 μK resolution. Should these investigations prove to be promising, efforts will be directed toward developing an ultrasonic tomographic system based on digital PPLL technology that would allow rapid 3-dimensional absorbed dose profiles in water and, possibly, other media. (H. Chen-Mayer, R.E. Tosh).

Proficiency Tests for Air-Kerma and Absorbed-Dose-to-Water Calibrations in ^{60}Co Fields. Following the completion of a new characterization of the NIST therapy-level ^{60}Co gamma-ray beams in terms of the radiation quantity air-kerma, proficiency tests were performed for the three AAPM-ADCLs, including tests of the ability to calibrate in terms of the radiation quantity absorbed-dose-to-water. These test involved shipping a previously characterized NIST reference-class ionization chamber to the ADCLs, with each participating laboratory calibrating the chamber in terms of air kerma and absorbed dose to water in a ^{60}Co gamma-ray field without knowledge of the value of the calibration coefficients determined at NIST. The values for the air-kerma and absorbed-dose-to-water calibration coefficients obtained by the ADCLs agreed with the value determined by NIST to within 0.2 %. Such tests, conducted on a periodic basis (typically every three years), ensure traceability between secondary laboratories and NIST. (R. Minniti).

X-Ray Calibration Range Measurements. The calibration and irradiation of instruments that measure x-rays are performed in the NIST x-ray calibration facilities in terms of the physical quantity air-kerma. Calibrations are performed by comparing the instrument to a NIST primary standard, which include four free-air chambers. Five reference radiation qualities were added to the nearly 100 qualities maintained at NIST in the three x-ray calibration ranges. The newest radiation qualities will allow an indirect comparison of a NIST primary standard with the BIPM for low energy x-rays. Air-kerma measurement comparisons with the BIPM and other primary standards laboratories are conducted for quality assurance. The ISO narrow spectrum series of reference radiation qualities maintained at NIST has been used to prepare for the EUROMET Project 545. This comparison will be conducted in two of the x-ray ranges in December of 2004. The results from an indirect comparison with the BIPM, which was a repeat of measurements performed in 1991 were submitted to the BIPM. In addition to participating in measurement comparisons, the NIST x-ray facilities are used to conduct proficiency tests for various NIST customers. NIST customers, who include secondary calibration facilities, chamber manufacturers, nuclear industry, Department of Energy, Department of Defense, private calibration facilities, medical facilities, and the FDA, request calibrations in terms of Gy/C for various reference-quality ionization chambers to achieve traceability to NIST. In addition to conducting routine calibrations and proficiency testing, the x-ray ranges have been used recently for research. The 300 kV range was used to evaluate a number of dosimeters and scintillator detectors for use in homeland security. Lower rate measurements were conducted which involved the use of a spectrometer and a large-volume pressurized chamber. The diagnostic equivalent M80 beam has been used to irradiate film for a dosimetry study for intravascular radiography. The Ritz and the Attix (mammography) primary chambers were used to measure air-kerma from a miniature x-ray source being designed for applications in medical radiology. (C.M. O'Brien)

Calibration of Low-Energy Photon Brachytherapy Sources. Small radioactive "seed" sources used in prostate brachytherapy, containing the radionuclide ^{103}Pd, ^{125}I, or ^{131}Cs, are calibrated in terms of air-kerma strength using the NIST Wide-Angle Free-Air Chamber (WAFAC). 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. More than 500 seeds of 32 different designs from 18 manufacturers have been calibrated using the WAFAC since 1999. 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 air-kerma strength to well-chamber response yields a calibration coefficient for the well-ionization chamber for a given seed type. Such calibration coefficients enable well-ionization chambers to be employed at therapy clinics for verification of seed air-kerma strength, which is used to calculate dose rates to ensure effective treatment planning. The Seltzer-Mitch chamber is an ionization chamber that was designed and built at NIST specifically to achieve greater efficiency than currently possible with commercially available chambers in prostate brachytherapy seed characterization. To understand the relationship between well-ionization chamber response and WAFAC-measured air-kerma strength for prostate brachytherapy seeds, emergent x-ray spectra are measured with a high-purity germanium (HPGe) spectrometer. Knowledge of seed spectra allows separation of well-ionization chamber response effects due to spectrum differences from those due to seed internal structure and self-absorption, which influence the anisotropy of x-ray emissions from the seed. The relative response of calibration instruments has been observed to depend on such anisotropy. To verify that seeds of a given design calibrated at NIST are representative of the majority of those calibrated in the past, several additional tests have been implemented. The distribution of radioactive material within a seed is mapped using radiochromic film contact exposures. The in-air anisotropy of seeds is studied by taking WAFAC and x-ray spectrometry measurements at discrete rotation angles about the long axis and the axis perpendicular to the mid-point of the long axis of the seed, respectively. The "air-anisotropy ratio," calculated from the results of angular x-ray measurements, has proven to be a useful parameter for explaining differences in well-chamber response observed for different seed models having the same emergent spectrum on their transverse axis. Such complete characterization of a seed is necessary for quality assurance of WAFAC measurements, and to maintain accuracy in the transfer of standards to secondary calibration laboratories. Anisotropy measurements, along with spectrum dependence in well-chamber response data, have been used to determine a reasonable tolerance criterion for acceptable variability in well-chamber calibration coefficients for a given seed design, and thus in a secondary air-kerma-strength standard established using well chambers. Data from two Accredited Dosimetry Calibration Laboratories (ADCLs) and the seed manufacturer, in addition to the results of NIST measurements, are compiled and checked as a function of time to ensure the continuous validity of the calibration traceability chain from NIST to ADCLs and manufacturers. (M.G. Mitch)

Absorbed-Dose Rate Measurements of Low-Energy Photon Brachytherapy Sources. Measurements of low-energy photon emitting brachytherapy sources are being performed at NIST using small-volume ionization chambers, micro-scintillators, radiochromic film and thin thermoluminescence dosimeters (TLDs). These measurements are being performed in a specially designed water phantom with the detectors either in water or covered with minimal layers of water-equivalent plastic. In 2004 absorbed dose rate measurements of a 50 kV x-ray probe continued in collaboration with McDaniels College students and faculty. In addition, measurements were continued of a novel ophthalmic applicator which employs high activity, annular ^{103}Pd source for the treatment of age-related macular degeneration. There are difficulties with these latter measurements due to the low energies involved (20 keV), probably related to interface effects between the detectors and their holders or housings. These problems are under investigation. (C.G. Soares)

Beta-Particle Emitting Ophthalmic Applicator Calibration Service. The NIST primary standard for beta-particle brachytherapy sources relies on extrapolation-chamber measurements, but quoted uncertainties are unacceptably high (>10 % at 2σ), mainly because of curvature of the current vs. air gap function, which leads to uncertainty in the measured absorbed-dose rate. Recent calculations have shown that this curvature can largely be removed through the application of a divergence correction to account for ionization losses at finite air gaps associated with the geometry of the source and extrapolation chamber. The divergence corrections were calculated using various Monte Carlo codes; most of the calculations used to determine the correction were done with EGSnrc Version 3. Air gaps between 0.01 mm and 0.5 mm were modeled, as well as three collecting-electrode materials: carbon, water, and D400 conducting plastic. Collecting-electrode diameters between 1 mm and 8 mm were modeled, and for each of these collecting-electrode/air-gap combinations three ^{90}Sr/Y beta-particle source geometries were modeled: a 1 cm diameter ophthalmic applicator, and 0.56 mm and 2.3 mm diameter seeds placed at a depth of 2 mm in water. The corrections are now being applied to all measurements since 1 January 2003. They are also being applied to prior measurements to assess the changes associated with the curvature in the current vs. air-gap function. An additional outcome of these investigations is a revised value for the electrode backscatter correction. Initial findings indicate the use of the new corrections will result in dose rates of ophthalmic applicators being increased by approximately 6.5 %. As a result of these calculations, the NIST uncertainty budget for these calibrations has been revised, and the expanded (k = 2) uncertainty has been lowered from 12 % to 7 %. A paper describing the divergence-correction determinations is being presented at the AAPM Annual Meeting. Three planar ^{90}Sr sources were calibrated in 2004 according to the new protocol, which has now been thoroughly re-documented for inclusion in the Division Quality Manual. (C.G. Soares)

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 irradiations of planar sheets of film at various depths in water-equivalent plastic are used to construct data sets which 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. The equipment used for these studies is augmented with two micro-scintillator detection systems, two automated three dimensional water tank scanning systems, various well-ionization chambers and two small fixed-volume ionization chambers. Collaborations were continued between NIST and Guidant for dosimetry of their ^{32}P wires, and over 3 sources and 25 well-ionization chambers were calibrated for Guidant and their customers. An international intercomparison for intravascular brachytherapy source dosimetry was initiated in 2004 with the Dutch standards laboratory NMi (Nederlands Meetinstitut). (C.G. Soares and M.G. Mitch)

D. Protection and Accident Dosimetry

Gamma-Ray Sources Used for Radiation-Protection Calibrations. Five gamma-ray sources are used for calibration of instruments and passive dosimeters, in terms both 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 110mGy/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. This includes US Navy and US DOE facilities, nuclear power plants and academic institutions. (R. Minniti).

Development of a Low-Level ^{137}Cs calibration Range. The design and assembly of a new calibration range has been completed. The range will be used for the calibration of ionization chambers and other gamma-ray detection instruments at very low air-kerma rates. Before, the lowest ^{137}Cs air-kerma rate available at NIST is 5 mGy/hr. The present development will provide for NIST-traceable calibrations at air-kerma rates down to ≈3 μGy/hr, approaching environmental-dosimetry levels. The new range consists of a ^{137}Cs irradiation source and an instrument-positioning system. Ionization chambers, as well as gamma-ray detection instruments, can be positioned precisely over distances from 60 cm to 450 cm. Data-acquisition software has been developed to interface with an electrometer, a pressure transducer, and a temperature meter. (R. Minniti)

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. The second-generation beta-particle secondary standard system (BSS2), which 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. The calibration service has been thoroughly re-documented for inclusion in the Division Quality Manual. In late 2004 or early 2005 NIST is scheduled to participate in EUROMET supplementary comparison of absorbed dose rate in tissue for beta radiation. (C.G. Soares, M.G. Mitch)

Tooth-Enamel Biodosimetry. Despite three international interlaboratory comparisons and an IAEA-coordinated project with participation of many EPR-dosimetry laboratories, a standardized EPR-dosimetry technique for tooth enamel has not yet been put forth. All EPR tooth-dosimetry techniques currently in use have certain aspects of them that are different. Since the uncertainties cited by the originators of the various techniques are always combined, it is not possible to assess and compare the quality of the different approaches so that a unified protocol can be developed. An alternative approach is to select one of the dosimetric techniques that performed well in the intercomparisons as the basis for a standardized technique from which improvements can be made. The first step in this approach is to examine the reproducibility, without loss of quality, to another laboratory. The EPR-dosimetry technique developed and routinely used at the Ukranian Scientific Center of Radiation Medicine (Drs. Chumak and Sholom) was selected for this study. The EPR-dosimetry technique that was developed and implemented at SCRM was successfully transferred to NIST. The spectrometer parameters for the technique corresponded to parameters of the original one, but were slightly better due to higher sensitivity of NIST's spectrometer. It was found that the differences between reconstructed dose and actual absorbed dose do not exceed 39 mGy. These results offer an optimistic outlook for the development of a standardized EPR-tooth dosimetry technique destined for a broader circle of users. (M.F. Desrosiers)

E. Homeland Security Applications

High-Dose Dosimetry Measurements and Standards for Homeland Security. The NIST Physics Laboratory collaborates under the direction of the OSTP with USPS, DOD (including AFRRI), DOE, FDA and USDA to ensure decontamination of anthrax in mail. Work has included: 1.) Calibration of electron-beam dose rates for the two industrial irradiation facilities used to treat contaminated USPS mail. 2.) Dosimetry of spore-kill validation experiments for the different electron beam parameters at the two industrial irradiation facilities used to treat contaminated USPS mail. 3.) Quantitative analysis of volatile organic chemicals and other potential irritants produced in mail packages during irradiation processing. 4.) Calibration of x-ray beam dose rates used to treat contaminated USPS large parcels. 5.) Dosimetry of spore-kill validation experiments for x-ray beams used to treat contaminated USPS large parcels. 6.) Preparation of mail-irradiation guidelines with AFRRI, FDA and industry representatives through the American Association for Medical Instrumentation (AAMI). (M.F. Desrosiers, J.M. Puhl, S.L. Cooper)

Follow-On Irradiation Efforts for Mail Security. [1] With a series of experiments informed by computational dosimetry, an optimized mail-irradiation process was previously developed by the group as a part of the White House OSTP Taskforce on Mail Irradiation. The refined process reduces the damage to potentially archive-able documents while maintaining a reasonable margin of safety. Having obtained White House approval, the group is pursuing Congressional adoption and USPS implementation of this optimized process. This is being driven by the following stakeholders: the National Archives and Records Administration (NARA) and the Advisory Committee on the Records of Congress. [2] In July 2004, the group hosted an interagency meeting on mail irradiation. Threats beyond anthrax were studied as well as the formation of an interagency council to be located within DHS. An experiment was designed a subsequently conducted at Sterigenics to investigate the efficacy of dose delivery with other packaging modalities for first class mail. [3] It is anticipated that in 2006, the irradiation of federal mail will be performed in a federal facility in Washington DC. The group is actively consulting with the USPS and their contractors to insure adequate technical specifications before construction and process validation before product release. [4] The USPS donated two Titan 10 MeV, 18 kW, electron linacs and associated equipment to the NIST Ionizing Radiation Division, intended as the basis for a radiation-processing test-bed facility that could help in the study of radiation mitigation of other threats, as well as for other industrial processes. The group is actively seeking the appropriately shielded space to set up the facility. (L.T. Hudson, M.F. Desrosiers, S.M. Seltzer, F.B. Bateman, P.M. Bergstrom)

Treatment of High-Risk Passenger Luggage to Reduce the Risk from Smuggling of Bioterrorism Agents. Passenger luggage is an easily accessible means for the introduction of biological agents into the US. Approximately 130,000 pieces of luggage arrive from foreign countries each day at 116 international airports. Given the current demonstrated threat environment, and the obvious vulnerability of US crops and livestock, the Animal and Plant Health Inspection Service (APHIS, then in the Department of Agriculture, now in the Department of Homeland Security) initiated through the Technical Support Working Group (TSWG) a feasibility study by NIST of the viability of using irradiation of high-risk passenger luggage to mitigate a wide range of pathogens that might be introduced either intentionally or unintentionally. The use of ionizing radiation offers several attractive features: luggage does not have to be opened (non-invasive process); concealed bioagents are treated; contamination risk to personnel and facilities is low; it can neutralize a variety of agents simultaneously; the process can be automated. NIST was asked to conduct this study because of its previous leadership and experience during the recent anthrax attacks on the US mail and its longstanding expertise in the areas of Monte Carlo code development, radiation dosimetry, post-irradiation handling and safety, materials effects, and radiation-processing quality control and assurance. NIST teamwork with USPS during the anthrax studies also permitted this project to gain access to the accelerator facilities of IBA in Bridgeport, NJ, for testing the irradiation of luggage and luggage contents. The study has been carried out in three phases, the first two of which were completed in 2003. Phase 1 involved the assembly of critical input data concerning pathogens and passenger luggage. In consultation with the Armed Forces Radiobiology Research Institute (AFRRI), pathogens were prioritized and the radiation-kill curves of bioagent and pests were compiled. Statistical data on passenger luggage were obtained from communications and visits with the Transportation Security Laboratory (TSL), William J. Hughes Technical Center, Atlantic City International Airport, NJ, where about 7000 pieces of unclaimed passenger luggage have been collected and characterized. TSL provided NIST with a random selection of 24 pieces of unclaimed luggage and their contents to be used in our testing, and shared information on the average density and range of densities derived from the TSL database. Phase 2 consisted of the development and verification of a coupled computational-experimental approach wherein dose distributions from Monte Carlo calculations were compared to NIST dosimetric measurements from commercial test irradiations at the IBA irradiator facility in Bridgeport, NJ. Three such runs have been made using 5 MV x rays at various absorbed-dose levels. The measurements involved a total of about 450 dosimeters strategically placed to determine the distributions of absorbed dose in various arrangements, both simple and geometrically complex, of irradiated phantoms and luggage. The Monte Carlo work included significant development of specialized modifications to existing codes and algorithms to best simulate the desired configurations and quantities, and numerous calculations were performed for testing and data development. Very good agreement has been achieved between the measured dose distributions of both homogeneous and heterogeneous product configurations and those from Monte Carlo simulations of the same experimental conditions. In particular, special attention was paid to the effects of high-atomic-number contents that could contribute either to unintentional dose sparing or to an intentional defeat of the process. These simulations were extended to investigate the possibility of imaging the luggage with the same beam used for treatment to detect possible defeat measures. The good agreement (better than about 10 %) between measurement and calculation permits a powerful extension of these computational methods as planned for Phase 3. Because of the success of Phase 2, virtual experiments can be performed without performing resource-consuming offsite experiments. These calculations can now define the limiting scenarios for bioagent and luggage configurations. Of interest is the processing function for an LD3 unit-load luggage container used on wide-body jets, which might be processed before the luggage is off-loaded. This information will permit belt speed to be set based upon a desired minimum dose, average density of the LD3 contents, and available beam current. Planned Phase 3 activities will include also validation tests for 7 MV x-ray beams and the data development for this commercially available and far more efficient process. Finally, Phase 3 calls for the development of specifications, procedures, and protocols for passenger-luggage treatment for use by responsible agencies and irradiation-equipment manufacturers and operators. An adaptive strategy is envisioned that will be flexible enough to adjust to changing threat levels or luggage configurations in real time with an open architecture for mitigating future threats. A final report will contain sufficient information to allow responsible agencies to make an informed decision on the choice of radiation-exposure level to be used at points of entry. (S.M. Seltzer, M.F. Desrosiers, P.M. Bergstrom, L.T. Hudson, D.J. Alderson, S.L. Cooper, J.M. Puhl)

Testing of Radiation-Detector Instruments for Homeland-Security Applications. A study involving the characterization of a large number of x-ray and gamma-ray detection instruments was completed in support of the Department of Homeland Security program at NIST. The measurements were performed at the NIST x-ray and gamma-ray calibration facilities maintained by the Radiation Interactions and Dosimetry Group. The exposure rate and energy response of the detectors was measured over a wide energy range by using calibrated photon beams from ^{60}Co (1.25 MeV) and ^{137}Cs (0.662 MeV) sources, and various highly filtered x-ray beams with mean energies ranging from 0.15 MeV down to 0.06 MeV. End users that benefit from this work, and for whom ANSI standards and Test and Evaluation protocols have recently been developed, include for first responders, Coast Guard, port authorities, and Customs personnel. Preliminary results were presented at the International Conference of the International Radiation Protection Association in May, 2004. (R. Minniti, C.M. O'Brien).

Gamma-Ray Exposure/Air Kerma from Sources Proposed for Testing Radiation Detectors for Homeland Security. A program of calculations has been undertaken to estimate the air-kerma rate, as a function of distance in air, that can be expected from the photons emerging from sealed sources containing pure ^{40}K, ^{57}Co, ^{60}Co, ^{67}Ga, ^{99m}Tc, ^{125}I, ^{131}I, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{201}Tl, ^{226}Ra, ^{228}Th, ^{232}Th, ^{233}U, ^{235}U, reactor-grade Pu, and ^{241}Am. Such sources have been proposed in recent ANSI standards and protocols for the testing of radiation detectors for homeland-security applications. The calculations predict the air-kerma rate, per unit of contained activity, as a function of distance in air, taking into account photon attenuation in proposed source windows and buildup effects in the air. Related calculations are being done to obtain information on the photon emission and air-kerma rates from large sources of highly enriched U, natural U, depleted U, and reactor-grade U to help in estimates of detectability with current instruments of smuggled nuclear material. (S.M. Seltzer)

Homeland Security Standards for X-Ray Screening Equipment. The Radiation Interactions and Dosimetry Group has been tasked by the Department of Homeland Security to facilitate the establishment of technical performance standards for x-ray screening equipment for federal purchasing decisions. At present, if a product is sold commercially, and if the vendor meets certain contracting requirements, they can be added to the GSA schedule. There is a growing sense of the immediate need for national consensus standards in the growing number of security situations that involve screening with x-ray devices. In January, a site visit to FAA's Transportation Security Laboratory (TSL) permitted review of the functional standards established for civil transportation security. Initial meetings have been held to chart a roadmap forward and key stakeholders have been identified. A review of existing standards related to x-ray screening has helped set priorities going forward. We are establishing standards-writing committees to codify DHS x-ray standards along four application areas: body screening, briefcase/purse/parcel screening in office buildings, luggage screening, and screening of large palletized cargo/containers/trucks. (L.T. Hudson, S.M. Seltzer, P.M. Bergstrom)

Guidelines to Limit Exposure in Radiological-Dispersal-Device/Improvised-Nuclear-Device Incidents. Technical consultation, planning, and review are being provided through participation in the Operational Guidelines Task Group (OGT). The OGT is an approved element of the interagency Consequence Management Subgroup led by the Department of Homeland Security to develop Protective Action Guides (PAGs) and operational guidelines for after a possible incident involving radiological-dispersal devices ("dirty bombs") or improvised-nuclear devices. The operational guidelines are levels of radiation or concentrations of radionuclides that can be compared to PAGs to quickly determine if protective actions for workers and the public need to be implemented. This activity is in response to Congressional direction to the DoE regarding the development of cleanup standards for response to dirty-bomb events. (S.M. Seltzer)

Measurement-Assurance Program for the Department of Defense. Since the early 1980s, NIST personnel have provided the Department of the Navy with a measurement-assurance program for their large-missile-motor x-ray inspection programs. On a yearly basis, the x-ray energy fluence of all the generators, 300 kV to 15 MeV, used in the inspection program that have minimum output contractual requirements are measured for compliance. This program also includes evaluation by calculation and visual confirmation of the image-quality indicators used in the transmission radiography (including film, real-time, and computed-tomographic modes of imaging) to verify that the inspection sensitivities specified by government contract are consistently met. During this year, NIST personnel performed the x-ray measurements on three generators at the Navy's off-loading site and on one generator at the Navy's test facility. X-ray measurements were also performed on two Navy-owned generators located at the contractor's manufacturing sites. Repair and replacement parts are no longer available for the original inspection equipment installed in the 1980s, necessitating numerous reviews of the replacement inspection equipment and subsequent comparisons of "before and after" imagery. NIST personnel have been actively involved in the evaluations of this modernization activity, whose goal is to maintain the same level of inspection sensitivities, thereby maintaining compatibility with the historical inspection image archive. (J.H. Sparrow)

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