EARLY HISTORY OF NIST IONIZING RADIATION PROGRAMS AND CIRMS

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Thank you , Mr. Chairman, I am pleased to have this opportunity, after a long absence, to return as an alumnus of "The National Bureau of Standards"(NBS), and to speak at this CIRMS meeting devoted to the "Impact of New Technologies on Radiation Measurement and Standards".

SLIDE 1 - TITLE

The title of my talk as shown in the first slide is:

"EARLY HISTORY OF NIST IONIZING RADIATION PROGRAMS AND CIRMS"

A talk on history presented at the "National Institute of Science and Technology" (NIST) is particularly appropriate where histories of NIST work in many subject areas have been created in the physical sciences and engineerings. This talk is very focussed on only one of those areas - ionizing radiation, and on the "EARLY" time period from 1928 to1988. 1988 was just when the National Bureau of Standards became the National Institute of Science and Technology. CIRMS was formed 4 years later. Since 1992, NIST and CIRMS have been working together with great effectiveness. They have been identifying the important national measurement and standards needs in uses of ionizing radiation in the radiation processing industry and elsewhere.

The EARLY HISTORY words in the title include the years immediately after World War II from 1945 to 1970 that have been called by some the "Golden Years of Physics". The same years are included in this history, but I prefer to call them the "golden age of the NBS Radiation Physics Division". Reference is made to that age in the cartoon in the next slide that was borrowed from the now-defunct Punch magazine.

SLIDE 2 - CARTOON

Note the man in the easy chair in deep thought and the 2 men at the bar one of whom states: "He says if he concentrates hard enough he can remember the golden age of the NBS Radiation Physics Division "

Before "concentrating hard enough" to recall some history, I reviewed current NIST work via Internet in such documents[1,2] as a 2002 Newsletter of the Technical Activities of the

"Ionizing Radiation Division".[1]

SLIDE 3 - PRESENT NIST GOAL AND STRATEGY

Slide 3 that was copied from the Newsletter states the goal and the strategy for meeting this goal:

"The goal is to provide the foundation of ionizing radiation measurements for our nation. The strategy for meeting this goal is to develop, maintain, and disseminate the national standards for ionizing radiation and radioactivity to meet national needs for health care, U.S. industry, and homeland security".

The three Strategic Focus areas are:First - Radioactivity Standards; Second - Neutron Standards and Measurements; Third - Radiation Dosimetry Standards

These comprehensive goals and strategies have a long history.

SLIDE 4 - HISTORY IN THREE TIME PERIODS

I outline that history[3,4,5] in this talk by summarizing the people and programs with x rays, gamma rays, and electrons from 1928 to 1988.The major subdivisions will be three time periods listed in this slide:
Period 1: 1928 to 1945 when establishment and many contributions of NCRP took place at NBS;
Period 2: 1945 to 1970 when two new betatrons were added to seven other radiation sources for research; and
Period 3: 1970 to 1988 when missions and science were accomplished with all sources.

I also will suggest from this early history the basis for the founding of CIRMS.

So with that introduction, let’s fasten our seat belts and start with the next slide:

PERIOD 1: 1928 TO 1945

SLIDE 5 - PERIOD 1: 1928 TO 1945

At the start of the period from 1928 to 1945, Lauriston S. Taylor was hired at NBS as a young - 28 year old - physicist to measure accurately dosages in roentgen units produced by x-rays and radium gamma rays. Taylor soon became Chairman of "The National Council on Radiation Protection and Measurements" with the acronym "NCRP"[6].

There followed thirty five years of active experimental research and theory on the design and application of measuring instruments and shielding of personnel against radiations. Those radiations were produced by electron and proton accelerators with energies up to 1 million volts but low beam intensities available at that time.. Taylor coordinated NCRP committees of scientists and engineers that studied and recommended guidelines subsequently published in internationally recognized reports and handbooks. These years and publications were interrupted by NBS staff reassignments to work on proximity fuse, radar and atomic bombs for the second world war from 1940 to 1945.

As stated in the NCRP web site, " the NCRP was reorganized and chartered by the U.S. Congress in 1964 as the National Council on Radiation Protection and Measurements"[6] and was relocated from NBS to NCRP offices in Bethesda, Maryland. It is appropriate to note here the major contributions Lauriston Taylor and NCRP have made to the nation. A rough measure of that contribution can be obtained from the large number, 1.8 million, copies of 140 NCRP handbooks and other formal reports distributed since 1931[6].

Near the end of this first period, Dr. Lyman J. Briggs, the third Director of NBS since its founding in 1900, had celebrated his 71st birthday. He submitted his resignation to Secretary of Commerce Wallace on June 25, 1945.Dr. Edward U. Condon[7],a first-rate theoretical physicist, was recommended as Brigg's replacement. He was formally appointed NBS Director on November 7, 1945, three months after the dropping of the Nagasaki atomic bomb and the end of the War with Japan to which he had contributed importantly[8].

PERIOD 2: 1945 to 1970

SLIDE 6 - PERIOD 2: 1945 - 1970

In the second period from 1945 to 1970, Dr. Condon's attentions initially were directed at budgetary and administrative matters, but were always based on need for new, modern, and fundamental research programs. His goal was to modernize NBS.

Consequently, his budgetary goals were substantial, but achievable because Congress and the country were eager to advance the science that had helped win the war. One result was a commitment for the Bureau, with the encouragement of Dr. Taylor, chief of the NBS Atomic and Radiation Physics Division, to acquire both a 50 Mev betatron and a 100 Mev betatron from the General Electric Company in 1948.

Condon's administrative goals were to reorganize NBS as a" principal mechanism for bringing the new physics to the Bureau"[9]. In1953, the Atomic and Radiation Physics Division, was "organized into two laboratories: the Atomic Physics Laboratory .... and the Radiation Physics Laboratory........"[9]

SLIDE 7 - PER. 2 - HIGH ENERGY RAD. SECTION

Condon and Taylor searched for a physicist with some betatron experience to head a High Energy Radiation Section in 1949 within RPL using the two GE betatrons. Fortunately for me, I had been involved in building and operating betatrons at Illinois for nine years. They made me an offer that I accepted. Thus I became another 28 year old physicist to head a new section, as Taylor had done 20 years earlier.

My section was named "High Energy Radiation Section"(changed in the 1950's from its start-up name, Betatron Section). Others from Illinois soon followed, such as John McElhinney, James Leiss, Everett Fuller, Samuel Penner, Jack Lightbody,Jr., and James O'Connell. I am pleased to say that Marshall Cleland from Washington University, St. Louis was one of those early recruits also.

After a decade, this new NBS group had accomplished a well-rounded combination of basic and mission-oriented research. Two sets of activities demonstrate the role played. First, the conversion of the 100 Mev betatron to a 180 Mev synchrotron by the General Electric Company in about 1952 made an accelerator that could generate a strong beam of synchrotron light tangential to the synchrotron electron beam in a vacuum that was uniquely important to atomic physics research. Dr. Robert Madden of the NBS Atomic Physics Division used this light source for much of his group's atomic research.

Second, the pioneering work of Lauriston Taylor, Harold Wyckoff, Joseph Motz, Ugo Fano, Lewis Spencer, and Martin Berger at energies below 1 Mev was seamlessly supplemented by the programs of the High Energy Radiation Section at energies above 1 Mev in radiation protection and personnel hazards assessment work. Two examples should be cited here of the active and productive collaborations. Koch and Motz wrote in Reviews of Modern Physics, (October, 1959)[10], an experimental and theoretical analysis and review of x-ray production by electrons (called bremsstrahlung). This review is still used by scientists and engineers as a reference source in interpretation of experimental results obtained with a spectrum of x-rays. Also, the extensive contributions made by the National Committee on Radiation Protection and Measurements led by Lauriston Taylor were assisted by members of the High Energy Radiation Section in NCRP Handbooks and Reports that dealt with both low and high energy radiations. One such report was NCRP Report 14 entitled "Protection Against Betatron-Synchrotron Radiations up to 100 Million Electron Volts" published in 1954.

SLIDE 8 - PER. 2: MOVE & NEW LAB PLAN

The success of this total program was recognized by the NBS administration when Lauriston Taylor retired from NBS and his position as head of the Radiation Physics Division. I was appointed to the position in 1962.

1962 was a critical time for NBS and the Division. A move of the NBS to Gaithersburg had been announced in 1960. This major move required a lot of planning of building spaces and issues. One of the biggest issues was the big deficiency in source strengths in radiation sources available in RPL from those source strengths that were becoming available and being used in U. S. industries. Our low source strengths had been regarded as adequate for 40 years of radiation protection work with humans. For example, even though the NBS betatron and synchrotron were high energy accelerators, they had time-averaged beam power that was low and measurable in milliwatts. However, most of the applications by industry to materials processing required high beam powers in the 100 to 1000 kilowatts range, but usually only at energies below 10 Mev per accelerated particle.

Taylor had encouraged the planning by the High Energy Radiation Section of a linear accelerator (linac). Thus was developed the plan for an L-Band linac that could produce 50 kilowatts of power at 100 Mev with peak energies of 140 Mev for the new laboratory as well as a 1.5 Mev electron Dynamitron with kilowatts of beam power and a 4 Mev electron Van de Graaff for lower energies.

The entire Division participated in the planning of a large building to accommodate new sources and most of the radiation sources operating in the DC laboratories. Dr. James Leiss supervised much of this planning and the linac. Of the original two large accelerators obtained from GE, the decision was made to surplus the 50 Mev betatron and move only the 180 Mev synchrotron.

PER 2: NBS RADIATION PHYSICS LABORATORY AT GAITHERSBURG

SLIDE 9 - PER. 2: GAITHERSBURG, MD.

After all the planning, the new building at Gaithersburg identified by number 245 was constructed with a total of 77,000 square feet of useable space. 70 percent of that space was located below ground level in order to take advantage of the shielding by the ground. Nine different radiation sources were moved from DC with only the linac and dynamitron being moved in directly from their manufacturers.

Details of the new facilities were assembled by the NBS public information staff with photographs and discussions with Laboratory staff. The results were printed in 1966 in a blue, 36 page booklet entitled: NBS Radiation Physics Laboratory[11].

A few pages from that booklet that show this attractive facility are:

SLIDE 10 - PER. 2: AERIAL VIEW OF NIST

for an aerial view of the Gaithersburg site of NIST;

SLIDE 11 - PER. 2: AERIAL VIEW OF RPL

for a portion of the aerial view that focuses on the Radiation Physics Laboratory;

SLIDE 12 - PER. 2: LIST OF FACILITIES

for a listing of radiation sources available in the new lab;

SLIDE 13 - PER. 2: 140 MEV LINAC

for a photo of the 140 Mev linear accelerator; and

SLIDE 14 - PER. 2: LINAC BEAM HANDLING

for a photo of the linac beam handling system. We were all convinced that the facilities were exceptionally good for addressing measurement and standards problems from a few kilovolts in energy up to 200 Mev.

At the same time in 1966 when the booklet was completed, I undertook to summarize what was known about the applications of high energy electrons. The results were published in a Science magazine article[12]. It was also the time I was nominated to be Director of the American Institute of Physics, then headquartered in my home town, New York City. I accepted the job when offered and left NBS on December 27, 1966. Dr. Randall Caswell was named Chief of the Radiation Physics Division and Dr. James Leiss was named Chief of a newly created Linac Radiation Division.

SLIDE 15 - PER. 2: ELECTRON SPECTROMETER

The next major accelerator project for the Division was the design and fabrication of the NBS electron scattering spectrometer described in an NBS report by Dr. Samuel Penner [13]. Required also was a 12-channel semi-conductor counter system for the spectrometer. [14] The spectrometer and counter system were needed to accurately define the energy spectrum of electrons scattered from targets placed in the linac electron beam, such as for experiments of elastic and inelastic scattering of electrons from nuclei.

The linac and other lower-energy facilities described in the blue booklet were actively and productively being used by staff and many guest workers for the remainder of Period

2(1945-1970).

PERIOD 3: 1970 to 1988 - MISSIONS AND SCIENCE

The pay-off for years of effort with all of the radiation sources in the Radiation Physics Laboratory came in the third period from 1970 to 1988. It was then that the staff pursued with enthusiasm the missions and science planned with the superb facilities. The missions included some of what Taylor called the bread and butter work. He meant, for example, the number of radioactive sources sold or the number of calibrations of ionization chambers made or the number of advisory committees in which staff members participated.. The science activities not only were an indispensible part of the missions; the science was also done to improve science knowledge itself. A measure of the quantity of both the science and missions are to be found in the administrative and publication records of NIST.

SLIDE 16 - PER. 3: 1970 - 1988 SELECTED CLASSIC PUBLICATIONS

For the purpose of this history and talk, I selected publications in five main areas of work, all of which were in my estimation of high quality and have become classics. They were:

A. Monte Carlo Calculations by Martin Berger;

B. Standard reference data from the work of Everett G. Fuller and of John Hubbell and others;

C. Development of a sealed water calorimeter for absorbed dose measurements with cobalt-60 gamma rays as described by Steve Domen;

D. Elastic and Inelastic Scattering of High-Energy Electrons from the linac using the electron spectrometer as described by Sam Penner;

E. Theory and Experiment of Electrons and Photons and their interactions with matter as exemplified by the publications of W.R. Dodge and Evans Hayward et al.

A. Monte Carlo Calculations

There were important legacies of the modernizing reorganization of NBS by the brief appearance from 1945 to 1951 of an outstanding theoretical physicist, Ed Condon, as director of NBS. One of those legacies was the recognition of the need for including significant theoretical effort in experimental programs. This was particularly important in the early work on radiation protection using very thick shielding barriers for which even experiments were sometimes inadequate. Thus it was that theoreticians, such as Ugo

Fano, Lewis Spencer, Martin Berger, Michael Danos, Haakon Olsen (as a guest worker), Leonard Maximon, Sidney Meshkoff and Steven Seltzer played continuing key roles in the programs of the Division.

For this talk, I have selected an article that demonstrates the seminal contributions of Martin Berger. With his 1963 paper[15], he "quite literally established the Monte Carlo calculation of charged-particle transport at the energies of interest in medical and radiation-protection physics. He is generally credited as being the father of modern electron and proton Monte Carlo methods. The methods he developed and the cross section data for which he was largely responsible are imbedded in nearly all of today's coupled photon/charged-particle Monte Carlo codes"[16].

B. Standard reference data

NIST publishes standard reference data extensively in the Journal of Physical and Chemical Reference Data, in over 80 scientific and technical data bases, and in other government reports. Early among these reports were "Photonuclear Data - Abstract Sheets 1955 - 1982" published in1983 by Everett G. Fuller and Henry Gerstenberg[17] and "Photon cross sections, attenuation coefficients, and energy absorption coefficients from 10 kev to 100 Gev" published in 1969 by John Hubbell[18]. Hubbell has referred to his classic and much-cited review of the principal processes by which photons interact with matter as his "defining publication". Fuller's collections, although more specialized, have also been widely used. The work of Fuller[17] and of Hubbell[18,19,20,21] had just begun a few years before the National Standard Reference Data System (NSRDS) was instituted in 1963.

C. Absorbed dose dosimetry:

Domen wrote: "Absorbed dose is widely used to quantify the medical or biological use of ionizing radiation. The output of a radiation therapy accelerator is calibrated by determining the absorbed dose rate in water, which has been chosen as the standard reference material because it has absorption and scattering properties similar to tissue. Traditionally, absorbed dose is determined from measurements with an ionization chamber[22, 2] and using a protocol, which gives the procedure along with numerous correction factors for determining the absorbed dose in water. It has been shown that the most nearly direct approach is with a water calorimeter. Yet this direct approach was not considered possible because of technical difficulties" [23-27].

Steve Domen, formerly of the NBS Radiation Physics Division and now a NIST guest worker, overcame these difficulties and developed a sealed water calorimeter over a twenty year period. His calorimeter was a one foot cube filled with purified water. He measured the temperature rise with small thermistors at a depth of 5 centimeters below the surface into which the gamma rays from a cobalt 60 source entered. A dose produced by the source of 1 Gray resulted in a temperature rise of 0.24 millidegree Kelvin to an accuracy of 0.5 %.[23,28,29]

D. Elastic and Inelastic Scattering of High-Energy Electrons

Penner wrote[30] : "Electron scattering can indeed provide basic information on nuclear structure. From elastic scattering studies comes information about nuclear sizes and shapes, and from inelastic scattering comes information about the energy level structure of nuclei, including the spin, parity, and transition strength of the excited nuclear states.................. In a typical experiment, the beam from the LINAC was impinged on a target of the material to be studied, and the scattered electrons passed through a solid-angle-defining slit. They then passed through a momentum-selecting bending and focusing spectrometer magnet, and were finally detected by a focal-plane array of small, solid-state detectors. Operated under computer control, the final output of such measurements was a plot of the number of scattered electrons per unit of energy per incident electron vs. the energy of the scattered electron for a given scattering angle or momentum transfer. The energy resolution of the whole instrument was 0.08 percent—sufficient for high-quality work............In collaboration with guest workers from MIT, the University of Maryland, Catholic University, American University, the University of Massachusetts, Virginia Polytechnic Institute, and the Laboratoire de 1'Accelerateure Lineaire, Orsay, France, quite a number of different nuclei were studied "[30] by the NIST team of Lightbody, Penner, and Fivosinsky. "An outpouring of basic research in nuclear physics came from the new instrument."[30,13,14]

One fundamental result of the information obtained with "a measurement of the elastic scattering cross-section from ^{12}C atoms. Together with the results of an earlier experiment involving lower momentum transfer allowed them to determine the shape of the ground-state charge distribution and the charge radius with substantially improved accuracy. The new value of the charge radius of the carbon nucleus was determined with an uncertainty estimated at 0.6%."[31] The value reported was 2.472 +or - 0.015 femtometers[32] ,where the unit, a femtometer, is 10^{-15} meter. This value of the rms charge radius was determined "to an accuracy significantly better than heretofore achieved."[32,33]

E. Photon and Electron Physics

Specific results that were also fundamental in nature are the experiments of W.R. Dodge and E. Hayward who examined the theory and experiment of bremsstrahlung, of real and virtual photon interactions with nuclei, and of elastic scattering of photons [34-40].Particularly elegant was the theory of Arenhoevel and Hayward on scattering of plane-polarized photons by the giant resonances of nuclei[34]. The experimental application by Hayward and Barber et al involved the generation of monochromatic 15.1 Mev plane-polarized photons by scattering bremsstrahlung through 90 degrees from a carbon target and then scattering the 15.1 Mev photons from the giant resonances of heavy nuclei The results obtained demonstrate that the "predictions of the dynamic collective model are qualitatively understood."[35,36].In other experiments, Dodge and Hayward et al used positrons from a target placed after acceleration of electrons in the first 6 accelerating sections and accelerated the positrons in the last 3 sections. The positrons were then annihilated in a second target (Be) to produce photons with energies detemined by the positron energies. These roughly monoenergetic photons were scattered by ^{12}C and ^{16}O. These authors were interested in measuring the nuclear elastic scattering because it "is a most fundamental nuclear interaction. It is of particular interest because of its special relationship to the total photonuclear absorption cross section, the absorption and scattering cross sections being derived from the same complex scattering amplitude" [37].

All of the contributions and applications with the linac from 1965 up to 1988 were made possible by the initial congressional hearings in 1959, at which the goal for the linac was expressed. The goal were "the assembly of basic data and measurements that make such applications possible ...."[41]. Unfortunately for further contributions after 1988 with the linac, the NBS administration decided that its overall goal for the NBS ionizing radiation program using radiations from the linac had been achieved. The linac was declared surplus and disassembled in January 1989.

The termination of the work with the linac at the end of time Period 3 is a fitting place to end this "Early History" and move on to a discussion of the "Radiation Industry Today and the Need for CIRMS".

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RADIATION INDUSTRY TODAY AND THE NEED FOR CIRMS

The radiation industry today is quite different from the industry during the period from 1928 to 1985. One significant difference is in the size of the units of measurement. Consider them first.

The unit Gray (GY) (i.e., 1 Gy = 100 rad) was invented because the rad (100 ergs per gram) as used in radiation protection of personnel was too small a unit as was the earlier unit, the erg per gram. Now users are required to use an even larger unit, the kilogray, kGy, in order to provide suitable units for measurements at the high doses encountered in processing of materials by electrons or x-rays.

SLIDE 17 AND SLIDE 18 - RADIATION PROCESSING

Based on this up-grade in units, consider the absorbed dose requirements for processing of various materials and functions in the low dose range from 0.1 kGy to 3.0 kGy as shown in the next slide (Table 1); and the dose range from 15 to 1500 kGy in the following slide (Table 2). These data supplied to me by Marshall Cleland in 2004[42], are up-dates of similar data contained in the 1966 Science article cited previously[12]. The list of processes in these two slides help define those of interest to industry today.

Another change in the processing industry is the concern against inducing side-effect radioactivities in the materials being processed by the intense irradiation needed to accomplish the primary effects in Tables 1 and 2. As shown in an article by Koch and Eisenhower entitled "Radioactivity Criteria for Radiation Processing of Foods" [43,44], the radioactivities can be minimized by keeping the x-ray, gamma ray, and electron radiation used for processing to energies below 10 Mev.

A final change in the industry is due to the recent development of high-power, high-energy electron accelerators with peak energies below 10 Mev that were not available during the time periods covered in this 2005 CIRMS report. However, Koch and Eisenhower in a 1964 report entitled "Electron Accelerators for Food Processing" [44] gave details of the economics of processing. The data then showed that electron accelerators were not competitive with cobalt-60 sources. That situation has definitely changed.

FORMATION OF CIRMS IN 1992
SLIDE 19 - FORMATION OF CIRMS

Under the leadership of Randy Caswell (then chief of the Radiation Physics Division), a mechanism for coupling with industry and the public in general was established in 1992 with the formation of a Council of Ionizing Radiation for Measurements and Standards(CIRMS).

"CIRMS is an independent non-profit council that draws together annually experts involved in all aspects of ionizing radiation to discuss, review and assess developments and needs in this field." [45]. Its success derives from the interaction between people with needs for measurements and standards and those that can satisfy those needs. The interaction is provided by an annual meeting of prepared presentations, workshops at those meetings, and a triannual issuance of a Measurement Needs Report prepared by a Science and Technology Committee [45].

This concludes my talk about the History of Ionizing Radiation work at NIST and its relevance to the formation of CIRMS.

ACKNOWLEDGEMENTS

This historical account of work with ionizing radiation at NIST was presented at the request of CIRMS members who are actively involved in applying some of the fruits of

that history. Because it is history, the samples of articles written decades ago and contained in the appendices may be limited in their present-day usefulness. They should be up-dated by consultation with the present leadership of the NIST Physics Laboratory and its Ionizing Radiation Division.

This history was also prepared for my own personal benefit. It allows me to thank the NBS staff with whom I worked closely, for their friendship and high-quality work.

It also allows me to apologize herewith for the long delay in preparing my account. After my employment at NBS from 1949 to 1966, my involvements were with the American Institute of Physics from 1967-1987 and with retirement after 1987. These involvements far away from NBS made me unaware of the need for my writing my views of NBS history. I assumed that others had done it long before me. I now know that assumption was wrong.

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7. "While at Princeton, he coauthored the Frank-Condon principle in molecular physics; developed the theory of radioactivity decay, with Ronald W. Gurney; a theory of optical rotary power; the theory of proton-proton scattering, with Gregory Breit; and the theory of charge-independence of nuclear forces, with B. Cassen. His definitive treatise on the theory of atomic spectra, with George H. Shortley, established his reputation as an outstanding theoretical physicist." (Page 437 from Reference 3)

8. "In 1937, Dr. Condon went to the Westinghouse Electric Corp. at Pittsburgh as associate director of research and there developed a program of nuclear research.

Appointed a consultant to the National Defense Research Committee in 1940, he helped organize the Radiation Laboratory at MIT, where America's microwave radar program was started, and wrote a basic textbook on the subject of microwaves for the laboratory. During the war he introduced and directed the microwave radar research program at Westinghouse. In April 1943 he went to Los Alamos at the request of General Groves as associate director under Dr. Oppenheimer. Later that year he was called to the Radiation Laboratory at the University of California to head the theoretical physics group working on the electromagnetic (mass spectrograph) separation of uranium isotopes". Toward the end of the war he started the nuclear reactor program at Westinghouse which later produced the power plant for the Navy's atomic submarine.(Page 437 from Reference 3)

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45. CIRMS Science and Technology Committee, H.W. Koch, Chmn., Report on National Needs in Ionizing Radiation Measurements, P. 1-65, January 1995

List of Appendices

Copies of reports and articles are included on the disk elsewhere for ease of reading historical items that may not be accessible otherwise:

App. A. **NIST Ionizing Radiation Division, Technical Acitivities 2002**

App. B. **Stephen M. Seltzer, Recent Dosimetry Activities, April 15, 2005. Report prepared for Consultative Committee on Ionizing Radiation (CCRI), May 18-20, 2005, Paris**

App. **C. H.W. Koch and J.W. Motz, Bremsstrahlung Cross-Section Formulas and Related Data, Reviews of Modern Physics, v.31, N.4, P. 920 - 955, October, 1959**

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App. E. **H.W. Koch, Electron Beams: National Bureau of Standards and the New Technology, Science, v.156, N.3773, P. 321 - 328, 21 April 1967**

App. F. **Martin Berger, Monte Carlo Calculation of the Penetration and Diffusion of Fast Charged Particles, Methods in Computational Physics, v. 1, P. 135 - 215, 1963**

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App. J-6. **M.N. Martins, E. Hayward, G. Lamase, X.K. Maruyama, F. Schima, and E. Wolynec, Experimental Test of the Bremsstrahlung Cross section, Phys. Rev., v.**

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App. K. **H.W. Koch and Elmer Eisenhower, Radioactivity Criteria for Radiation Processing of Foods, Advances in Chemistry Series 65, September 16, 1965 ACS Symposium, P. 86-108, 1967**

App. L. **H.W. Koch and Elmer Eisenhower, Electron Accelerators for Food Processing, Proceedings of an International Conference, Radiation Processing of Foods, Boston, 1964, Pub.1273 NAS-NRC, Washington, DC, P. 149-180, 1965**

App. M. **CIRMS Science and Technology Committee, H.W. Koch, Chmn., Report on National Needs in Ionizing Radiation Measurements, P. 1-65, January 1995**