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DISCLAIMER

FAST NEUTRON DOSIMETRY

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USDOE Report No. DOE/EV/01105-298

Progress Overview For the Period

1 July 1982 Through 30 June 1983*

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I. INTRODUCTION

The past year can best be described as transitory in nature. S.J. Goetsch completed the comparison of the multi-dosimeter technique applied to in phantom measurements vs. a Monte-Carlo transport calculation. While described in several USDOE Reports issued over the last several years, a most complete discussion can be found in his thesis which was published as a Medical Physics Report (WMP-168). The construction of the hemispherical LET counter was completed. After extensive testing, LET spectra were measured for 14.8 MeV neutrons irradiating A150-plastic, graphite and lead. These preliminary data demonstrate a substantial improvement over the cylindrically symmetric device previously reported in WMP-121, DOE/EV/01105-273 and 274.

Continuing effort was expended to investigate the effect of mixed beams of neutrons and photons. A unique pulse structured irradiation procedure was employed in the most recent measurements. The synergistic effect of simultaneous versus sequential irradiation was confirmed.

On more theoretical grounds, the stochastic precursors to kerma and collision kerma were conceptualized. These defined quantities provide a connection analogous to that energy imparted has with absorbed dose. While not introducing any 'new' information, a substantial improvement results in the logical framework of radiation dosimetry.

In previous neutron dose measurements at 14.8 MeV, the dose inferred from the graphite proportional counter was in substantial agreement with neutron fluence and A150-plastic ionization chamber values. All results were based upon a common set of kerma factors. Recent carbon microscopic cross-section measurements at Lawrence Livermore National Laboratory (LLNL) made at 14.1 MeV resulted in a

kerma factor substantially lower than published tabulations. We measured the carbon kerma factor at LLNL with the graphite counter. These results confirm the LLNL cross-section measurements and demonstrate the significant neutron energy dependence in this energy region.

In summary, several aspects of neutron and related photon radiological physics are being actively investigated. These research topics relate to measurement techniques, basic data values and theoretical discussions. In addition, a modest radiobiological effort is pursued concurrently. The unique coupled neutron/photon source provides an excellent tool for this latter work.

II. PROGRESS FOR THE PERIOD 1 JULY 1982 THROUGH 30 JUNE 1983

A. Carbon Neutron Kerma Factor Determinations at 14.1 MeV (DOE/EV/01105-300)

During recent years, we have investigated the applicability of miniature proportional counters constructed of various materials for absolute neutron dose determination. Specifically in USDOE Report No. DOE/EV/01105-293 (1982), A150-plastic and graphite walled counters were employed to measure neutron doses at 14.8 MeV. In Report No. 294 (1982), these same instruments were used to deduce the fractional kerma factors for carbon and oxygen at 14.8 MeV. These results showed excellent agreement between values determined with the graphite and plastic-walled counters and conventional ionization chamber results. While the agreement for the A150-plastic walled devices was anticipated, that with the carbon-walled counter was surprising. The neutron cross section for interactions in carbon is substantially less well known than for hydrogen, which produces most of the kerma in A150-plastic (Caswell, 1980).

At this juncture, a collaboration with H.H. Barschall, R.C. Haight, and J.C. McDonald was initiated. Previous measurements by Haight et al. (Haight, 1983) of the carbon microscopic cross-section at 14.1 MeV resulted in a kerma factor substantially less than calculated by either Caswell or Plechaty (Plechaty, 1978). Otherwise, McDonald (McDonald, 1982) reported excellent agreement amongst calorimetric, ionization chamber and activation analysis measurements on the same neutron source. The present report discusses measurements at 14.1 MeV on the Lawrence Livermore National Laboratory neutron source in a geometry similar to that employed by Haight. The determined carbon kerma factor value of $0.178*10^{-8}$ cGy cm^2 is in reasonable (6%) agreement with Haight's value of $0.189*10^{-8}$ cGy cm^2.

Obviously, microscopic cross-section values for carbon in the 14-15 MeV energy region exhibit a significant energy dependence. Detailed knowledge of the kerma factors in this energy region is important to the fusion energy program and biological applications.

B. Neutron/Gamma Dose Estimates: Ion Chamber Measurements vs. Monte Carlo Calculations (DOE/EV/01105-303)

As an energetic neutron beam penetrates matter, extensive changes occur in the energy fluence distribution. This is accompanied by the production of a photon energy fluence distribution whose spatial occurrence is not identical with that of the neutron energy fluence. The great similarity in dose response of muscle-like materials makes indistinguishable the neutron and photon energy fluence in terms of muscle dose. Yet the biological response variation for constant dose between neutrons and photons demands a resolution of these dose components.

Taking advantage of the variability of response of non-muscle-like materials, we have explored a multi-dosimeter technique for resolution of these dose components in a water phantom (Attix:265 (1979) and Goetsch:290 (1982)). These somewhat limited physical results were compared to an extensive Monte-Carlo transport calculation in a similar irradiation geometry by Goetsch (Goetsch:281 (1981)).

In the present Report, 303, we present the results of measurements in water phantom at depths of 3.5, 7.5, 10, 15 and 20 cm. Neutron and photon dose components were determined on the beam axis and perpendicular to it. A two-dimensional dose profile was generated and compared to the transport calculations. A new dosimeter displacement correction factor was applied to the data. These dose determinations were compared to coupled neutron/photon transport calculations and were in substantial agreement for the planar neutron dose profiles. However, the photon dose profile is only in quantitative agreement; the transport calculations being uniformly less than the measured values. The calculations include a planar source of energetic photons perpendicular to the beam which replicates the photon energy fluence emitted from the shield-collimator.

Undoubtedly, failure to include all photon sources in the transport calculations contributed to the quantitative disagreement. Complete calculational simulation of the specific experimental geometry would be extremely expensive and useful only for that geometry. The close correspondence between the relative experimental and calculated dose profiles is confirmation of the validity of the measurement techniques.

C. Operation of a Hemispherical Detector for LET Measurements (DOE/EV/01105-301)

Microdosimetric measurements have traditionally focussed upon energy loss distributions due to charged particle chord traversals in a spherical cavity - a 'Rossi counter'. In an earlier effort (Brandan, 1980), we invented a detector to measure the distribution in energy loss for constant pathlength, i.e. the stopping power. This device suffered from two major problems: (1) the detector had cylindrical symmetry and thus measured only a subset of the complete distribution and (2) various difficulties in the proportional counter (ΔE detector) and CsI(Tl) (E detector) prevented detection of the higher-Z component of the low-energy particles. A new instrument was invented and a conceptual design description made in USDOE Report No. DOE/EV/01105-288 (1982).

This new device is of hemispherical design thus possessing spherical symmetry when bombarded parallel to its rim by an unpolarized beam of neutrons. Again the ΔE detector is a gas proportional counter while a CsI(Tl) crystal acts as the E detector. Significant improvements in the detector designs were implemented. This was confirmed in resolution and gain measurements described in this years progress report. Preliminary LET_{∞} spectra were also measured for 14.8 MeV neutron bombardment of A150-plastic, graphite and lead walls. While these spectra were of a survey nature, excellent agreement with a calculated LET_{∞} spectrum was achieved (Edwards and Dennis, 1975).

D. Mixed Neutron-Photon Radiobiology (DOE/EV/01105-302)

Response of biological systems to radiation fields is not only dependent on the radiation quality employed, but on the temporal mixture of the radiation components. We demonstrated in Report

DOE/EV/01105-282 that sequenced irradiation by 14.8 MeV neutrons and ^{60}Co photons produces the same net response as would be expected from independent addition of dose response affects from each beam type. On the other hand, simultaneous irradiation with a mixture of selected high and low LET components produces an effect consistent with what might be expected for a different, more biologically toxic, beam quality. In this case, net biological response is different than would be predicted from independent dose addition, even though the time-averaged beam qualities are the same for either case.

Use of pulsed irradiation methods described in DOE/EV/01105-302 further enabled us to reduce possible dose rate related effects in confirming our earlier experience with simultaneous versus sequential irradiation of V79 Chinese hamster cells. It is suggested that continued study of the effect of varying the pulse length in sequential irradiation with different beam types may aid in determining the minimum time between sequenced pulses that will yield the composite biological effect observed for simultaneous irradiation. This measure of effective repair time will provide insight into the timing required for optimal biological response in situations where multiple beam types are employed and will help in correlating response as a function of composite beam quality.

E. Fundamental Dosimetry Concepts, Quantities and Units (DOE/EV/01105-299, 305)

During the year theoretical contributions were made on two subjects of fundamental importance in radiation dosimetry.

The first was a paper entitled "Energy imparted, energy transferred, and net energy transferred," which defines a new stochastic quantity energy transferred, in terms of which the familiar

non-stochastic quantity kerma is then defined. In like fashion the stochastic quantity net energy transferred is defined to serve as the precursor for collision kerma. The latter quantity is that part of the kerma that is not lost through radiative interactions by secondary electrons. Thus collision kerma is less than kerma for γ-ray fields, but the two quantities are equal for fields of neutrons since their heavy secondary charged particles emit negligible bremsstrahlung. For the first time it is now possible to show in a simple mathematical way the relationship of absorbed dose to kerma and collision kerma under charged-particle equilibrium conditions. The logical under-pinnings of radiation dosimetry are thereby strengthened, and its teaching becomes more straightforward and easier to understand.

The second conceptual clarification is contained in a Communication (accepted for publication in Health Physics) dealing with the quantity dose equivalent and its special unit the sievert. Many workers in radiation protection have been confused and disturbed by the seeming lack of logic involved in defining the sievert as being equal to 1 J/kg while the gray is also equal to 1 J/kg. This paper points out the reason for the apparent paradox, and suggests an optimal remedy if any further change in the definition is contemplated. However the present situation is tenable, and is certainly preferable to the other revisions that have been suggested, e.g., by Ruby (1983).

F. Bone Blood Flow Measured by ^{41}Ar Clearance Formed by ^{44}Ca(n,α) ^{41}Ar (DOE/EV/01105-304)

We have applied a novel technique to quantify regional blood flow in bone. An inert gas, ^{41}Ar, is produced regionally in bone by means of the ^{44}Ca(n,α) reaction using 14.3 MeV neutrons. The movement of Ar from the bone is assumed to be blood-perfusion limited. Determination of regional bone blood flow could be an important diagnostic tool for the study of micro-emboli such as occur in the femoral head.

^{41}Ar is characterized by a 110 min half-life and emits a well resolved photon of 1293 keV. Unfortunately the low cross section of 40 mb and isotopic abundance of 2% require fast neutron doses of 50-200 cGy locally. Nonetheless, bone perfusion was measured for dead and live rats. The determined perfusion values were in the range of 3-20 ml/100 ml of argon distribution volume. It was also noted that the calcium content of bone could be deduced simultaneously from the production of ^{44}K by means of the $^{44}Ca(n,p)$ reaction.

III. PUBLICATIONS AND PRESENTATIONS: 30 June 1982 - 1 August 1983

A. Reports

Wisconsin Medical Physics Report WMP-153, Progress Report to the USDOE on Contract No. DEAC02-76EV01105.A007 for the period 1 October 1982 through 30 June 1983. This report included the following eleven parts:

DOE/EV/01105-287 Review of Radiation Dosimetry Research at the University of Wisconsin During 1961-1982.
J.R. Cameron, P.R. Moran and F.H. Attix

DOE/EV/01105-288 Design Criteria for a Hemispherical Detector for LET Measurements.
M.C. Schell, P.M. DeLuca, Jr., D.W. Pearson and F.H. Attix

DOE/EV/01105-289 Preliminary Study of a Gamma-Ray "Telescope" Relevant to Neutron Personnel Dosimetry
F.H. Attix, A. Niroomand-Rad, P.M. DeLuca, Jr., F. López, D.W. Pearson, and B.R. Paliwal

DOE/EV/01105-290 Revised Neutron/Gamma Dose Estimates in a Water Phantom for 14.8 MeV Neutrons.

S.J. Goetsch, F.H. Attix and D.W. Pearson

DOE/EV/01105-291 Characteristics of A-150 Plastic Equivalent Gas in A-150 Plastic Ionization Chambers for p(66)Be(49) Neutrons.
M. Awschalom, I. Rosenberg, R.K. Ten Haken, D.W. Pearson, P.M. DeLuca, Jr., and F.H. Attix

DOE/EV/01105-292 Characteristics of Various Tissue and A150-Plastic Equivalent Gas Mixtures for Microdosimetric Applications.
P.M. DeLuca, Jr., M.C. Schell, D.W. Pearson and F.H. Attix

DOE/EV/01105-293 Applicability of Paired Graphite and A150 Plastic Proportional Counters to Neutron and Photon Dose Determinations.
P.M. DeLuca, Jr., M.C. Schell, D.W. Pearson, and F.H. Attix

DOE/EV/01105-294 Fractional Neutron Kerma for Hydrogen, Carbon, Nitrogen and Oxygen Deduced from Microdosimetric Measurements.
P.M. DeLuca, Jr., M.C. Schell, D.W. Pearson, and F.H. Attix

DOE/EV/01105-295 Rat Mammary Cell Survival Following Irradiation with 14.3-MeV Neutrons.
P.A. Mahler, M.N. Gould, P.M. DeLuca, Jr., D.W. Pearson, and K.H. Clifton

DOE/EV/01105-296 Survival of Parenchymal Hepatocytes Exposed to 14.3-MeV Neutrons.
R.L. Jirtle, M.N. Gould, P.M. DeLuca, Jr., and D.W. Pearson

DOE/EV/01105-297 Response of Some TLDs to 14.8-MeV Neutrons.
D.W. Pearson

B. Journal Publications:

Higgins, P.D., DeLuca, Jr., P.M., Pearson, D.W. and Gould, M.N., 1983, V79 Survival Following Simultaneous or Sequential Irradiation by 15-MeV Neutrons and ^{60}Co Photons, Rad. Res. 95 (45-56).

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Awschalom, M., Rosenberg, I., Ten Haken, P.K., Pearson, D.W., Attix, F.H., and DeLuca, Jr., P.M., 1982, Characteristics of A150 Plastic-Equivalent Gas in A-150 Plastic Ionization Chambers for p(66)Be(49) Neutrons, Med. Phys. 9 (884-887).

Jirtle, R.L., DeLuca, Jr., P.M. and Gould, M.N., 1982, The Survival of Rat Hepatocytes Following 14.3 MeV Neutron Irradiation, Rad. Res. (in press).

Attix, F.H., 1983, Energy Imparted, Energy Transferred and Net Energy, Phys. Med. Biol. (in press).

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DeLuca, Jr., P.M., Schell, M.C., Pearson, D.W., Higgins, P.D., Attix, F.H., 1983, Performance Characteristics of A150-Plastic-Equivalent Gases in A150-Plastic Proportional Counters for 14.8 MeV Neutrons, Med. Phys. (submitted).

C. Presentations and Proceedings: (Speaker Underlined)

DeLuca, Jr., P.M., Attix, F.H., Pearson, D.W. and Schell, M.C., Microdosimetric Techniques Applied to Fast Neutron Measurements, April 1983, "The Neutron Biological Effects--Hazards and Medical Applications," Spring Symposium of Great Lakes Chapters of the Health Physics Society and the American Association of Physicists in Medicine, Detroit, MI. (This paper was judged the "Best Scientific Presentation")

Goetsch, S.J., Pearson, D.W. and Attix, F.H., Comparison of Monte Carlo Calculations and Ion Chamber Measurements of Dose in Phantoms for 14.8 MeV Neutrons, April 1983, "The Neutron Biological Effects--Hazards and Medical Applications," Spring Symposium of Great Lakes Chapters of the Health Physics Society and the American Association of Physicists in Medicine, Detroit, MI. (This paper was judged the "Best Student Presentation")

D. Thesis:

Goetsch, S.J., Neutron/Gamma Dose Separation by the Multiple Ion Chamber Method, Ph.D., May 1983, University of Wisconsin-Madison, available also from University Microfilms, Ann Arbor, MI.

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