PROPOSED NATIONAL BUREAU OF STANDARDS PROGRAM FOR THE CALIBRATION OF INSTRUMENTS USED IN HIGH-ENERGY ELECTRON AND X-RAY BEAMS*

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The National Bureau of Standards (NBS) recently started a program that is to lead to the establishment of an absorbed-dose calibration service for high-energy x-rays and electrons. It is the purpose of this paper to acquaint the reader with the two phases of this program: (1) the uniformity check of the calibrations performed by the users of high-energy electron beams and (2) the long-range research and development plans connected with the future absorbed-dose instrument-calibration service for high-energy x-rays and electrons

THE UNIFORMITY CHECK

This program is designed to tide the users of high-energy electron accelerators over the period during which NBS will not be able to offer calibrations against an absolute absorbed-dose standard As previously announced,[1,2] the program consists of the following service: Starting in July 1967, NBS is mailing, on a regular schedule, Fricke dosimeter units to all institutions desiring participation in this service. The dosimeter units are shown in FIGURE 1. Each unit consists of a spectrophotometer cell of radiation-resistant far-ultraviolet silica glass filled with ferrous sulfate solution, stoppered, sealed with a plastic band, and placed in a small polystyrene parallelepiped. At least four dosimeter units are mailed to each participant—two as controls and two to be exposed in a 10 × 10 cm field to doses between 3,000 and 8,000 rads from electrons of energy between 5 and 50 mev The exposure phantom and exposure geometry are those recommended by the Subcommittee on Radiation Dosimetry of the American Association of Physicists in Medicine (AAPM).[3]

The participants are requested to return the unopened units to NBS not later than the third workday after their receipt and to state on an enclosed form the dose administered to each cell (as measured by them), the field size, energy, details of beam-broadening method, type of collimator, and type of machine used. Upon return of the cells, NBS determines the difference in optical absorbance between the irradiated and the unirradiated cells, and from this information, estimates the actually administered dose, using the G value recommended by the AAPM Subcommittee[3] and corrections for the disturbance of the radiation field by the glass

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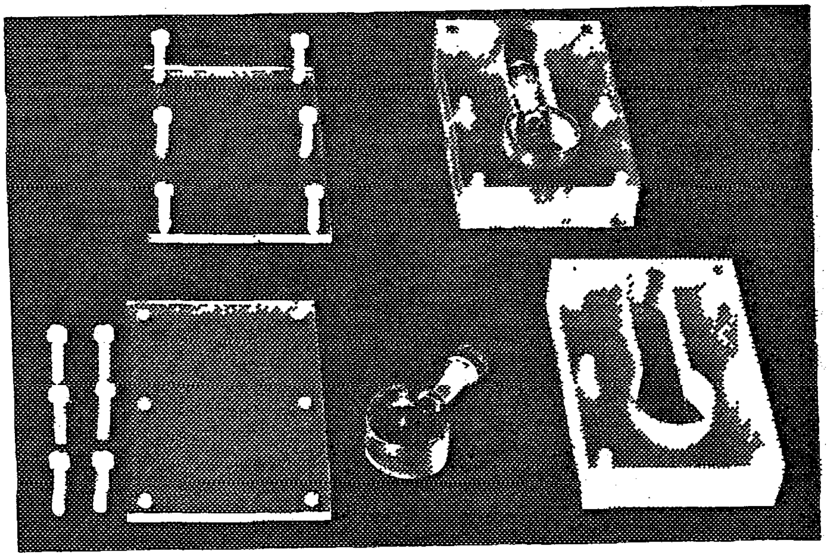

FIGURE 1 The Fricke dosimeter unit

of the spectrophotometer cells.[4] NBS then submits a review of all results to each of the participants, without divulging institutional identities

PROPOSED RESEARCH AND DEVELOPMENT OF AN ABSORBED-DOSE INSTRUMENT CALIBRATION SERVICE

The final goal of this project is the establishment of a service for calibrating suitable instruments belonging to the users (in this paper, referred to as "transfer instruments") in terms of absorbed dose in a specified material, for both x-rays and electrons, in the energy range from about 1 mev to 50 mev The program is just getting underway at the time of this writing As it is envisaged now, it consists of several distinct phases referring to the calibration setup, the NBS standard instrument, the NBS working standard, and the transfer instrument (or instruments) for the user In the following, the general lines of approach will be discussed briefly for each of these phases.

The Calibration Setup

Presently, NBS is in a position to produce narrow pencils of monoenergetic electron beams of relatively high currents over the entire energy range of interest for this program For dosimetry applications, a system of beam broadeners and collimators will be installed for the electron beams, and targets, filters, and colmating systems will be provided for the production of bremsstrahlung beams. Through the use of special beam-handling systems, the installations will be made sufficiently flexible to permit the dosimetry applications of the NBS accelerators without undue interference with other programs already under way on these machines. The work on this phase will include a critical evaluation of the designs presently employed by the users of high-energy electrons and x-rays.

The NBS Standard Instrument

It is generally agreed that calorimetry provides a direct, though not always easy, method for measuring absorbed dose in a material.[5-7] NBS decided to build a calorimeter as the standard instrument for measuring absorbed dose and to calibrate the laboratory (transfer) instruments of the users against this calorimeter Such a calibration will consist in determining the reading R_{trans} (in units appropriate to the instrument of choice) of a suitable transfer instrument in its calibration block, under conditions for which the NBS calorimeter indicates an absorbed dose D_{cal} (in rads) in the calorimeter material. The calibration factor, c.f , for the given field conditions is then given by

$$\text{c.f.} = \frac{D_{cal}}{R_{trans}} \tag{1}$$

In the following, some of the reasoning will be given upon which the choice of a calorimetry material was based for the case of electrons †

Ideally, the calorimeter material of choice would be one identical in composition to the material in whose response the user is interested, since, in this case, the calibration factor would be all that is required for computing the absorbed dose in the material of interest If the two materials are different, the absorbed dose in the material of interest (D_{mat}) due to an electron beam of energy T is obtained from the dose in the calorimeter substance (D_{cal}) as

$$D_{mat} = D_{cal} \frac{\overline{s(T)_{mat}}}{\overline{s(T)_{cal}}} \tag{2}$$

where $\overline{s(T)_{mat}}$ and $\overline{s(T)_{cal}}$ are weighted averages of the stopping powers of the two substances for electrons of energy T, taken over the spectral distributions inside the materials, which, in general, are not identical. The larger the difference in the atomic number of the two materials, the larger the difference in their stopping powers and in the spectra involved in the averaging procedure Therefore, for a given accuracy required in the knowledge of the absorbed dose in the material of interest, the larger the differences in the atomic number of the two materials, the more accurate would have to be the knowledge of the stopping powers at a given

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†The case of electrons is singled out here, since initially it is planned to use the calorimeter in an electron beam.

electron energy, and the more accurately would one have to know the spectral distribution.

Inasmuch as a large number of users of high-energy x-rays and electrons are concerned with the effects of these radiations in low-atomic-number materials, and specifically, in living tissue, it was decided to build an absorbed-dose calorimeter of low atomic number. The three materials considered were water, carbon, and a plastic, such as polystyrene. In TABLE 1 are shown the relative mass stopping powers due to collision losses for muscle and carbon (s_C^{muscle}), muscle and water ($s_{H_2O}^{muscle}$), and muscle and polystyrene (s_{polyst}^{muscle}), quantities that influence the choice of the calorimeter substance. While radiation losses are not negligible for the higher energies shown, they would not affect the absorbed dose materially, and thus are not included here. The table shows that, over the considered energy range, there is no dependence of the stopping power ratios on energy. Therefore, the error introduced by neglecting possible differences in the electron spectra inside the calorimeter built of one of these substances and inside the tissue of interest would not be appreciable. Equation 2 then takes the form

TABLE 1
CHOICE OF CALORIMETER SUBSTANCE

T (mev)	s_C^{muscle}	$s_{H_2O}^{muscle}$	s_{polyst}^{muscle}
1	1.13	0.99	1.02
2	1.13	0.99	1.03
5	1.13	0.99	1.02
10	1.12	0.99	1.02
20	1.12	0.99	1.02
50	1.12	0.99	1.02

$$D_{mat} = D_{cal} \cdot s(T)_{cal}^{mat} \qquad (2a)$$

where $s(T)_{cal}^{mat}$ is the relative stopping power of the two materials for the incident electron energy T, a quantity that is known to better than two percent.[8]

From TABLE 1, one may also conclude that the correction that would be required in the computation of the absorbed dose in the tissue from the absorbed dose in the calorimeter would be only about 1% for a water calorimeter, 2% for a polystyrene calorimeter, and more than 12% for a graphite calorimeter. Thus, for the users interested in absorbed dose in living tissue, a water calorimeter would give the most direct and the carbon calorimeter the least direct information of absorbed dose from an electron beam. Yet, not all materials lend themselves equally well to use as substances for absorbed-dose calorimetry. One important factor in deciding on a calorimeter substance is the fraction of the radiation energy that is utilized in chemical reactions rather than in a temperature rise. No [illegible] losses due to chemical reactions have been observed in water or carbon.[6] Thus, from this standpoint, either of these substances would be suitable. However, a liquid requires a container, whose walls are likely to disturb the radiation field, particularly if it has to be chosen also with attention to suitable calorimetric properties. This precludes the use of a water calorimeter as an absorbed-dose standard of high accuracy. On the other hand, the question of whether or not a polystyrene calorimeter would be feasible could be decided only after a better evaluation of the endothermic reaction of electrons with polystyrene. Initially, NBS is building a carbon calorimeter, using a graphite block of a thickness that can be adjusted according to radiation type and energy and isolating in it a small graphite calorimeter volume. Other calorimeter substances may be tried in the future.

The NBS Working Standard

For routine absorbed-dose calibration work, it is planned to employ a working standard such as a cavity chamber or one of the solid-state devices that is more convenient to use than the standard absorbed-dose calorimeter. Since the working standard will be calibrated against the calorimeter using the identical radiation setup, its choice will be guided simply by considerations of instrument reliability, reproducibility, and convenience.

The Transfer Instrument

NBS is carrying out investigations of the characteristics of existing dosimetry systems in an effort to arrive at specific recommendations for instruments that will be accepted by NBS for calibration in terms of absorbed dose. Because of the differences from machine to machine in the radiation fields produced within a phantom by electrons or bremsstrahlung produced at identical accelerator energies, field size, and shape, and external filtration in the case of bremsstrahlung, two approaches are possible for the choice of a transfer instrument suited to serve as the user's laboratory standard: Either one may choose an instrument with a response that is independent of the changes in the radiation spectrum caused by differences in machine geometry beyond the user's control or one may specify the radiation spectrum inside the calibration phantom. These two approaches will now be considered briefly for the case of high-energy electrons.‡

TABLE 2 shows the stopping powers due to collision losses in carbon relative to those of a number of possible transfer-instrument materials, quantities that influence the choice of the transfer-instrument substance. There is a trend with

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‡The bremsstrahlung case need not be discussed separately, since in principle it reduces to the electron case, instrument response being due mainly to the electrons produced by the incident photons in the phantom surrounding the instrument.

energy for air,§ but none for water and the solid a fact that is well known. This means that if the relative stopping powers are, indeed, an indication of relative instrument response, even large differences between the radiation fields used for the NBS calibration and those employed by the user might be immaterial if the transfer instrument were, say the Fricke dosimeter, a liquid or solid dye system, or a lithium fluoride (LiF) thermoluminescence system However, an ionization chamber could be used only if the radiation spectrum at the instrument during calibration were made to match the spectrum during use closely enough for the correction factor to be the same This procedure is employed routinely in the low-energy exposure calibrations of the condenser type of ionization chamber. There, NBS specifies the "beam qualities" for which calibrations are being offered, and the user chooses the ones best suited to his purposes. For high-energy electron and bremsstrahlung beams, it is planned to arrive at spectral characterizations involving spatial field characteristics, for instance, in the form of central and off-axis depth-dose information

TABLE 2
CHOICE OF TRANSFER-INSTRUMENT SUBSTANCE

T (mev)	s^{C}_{air}	$s^{C}_{H_2O}$	s^{C}_{LiF}
1	0.98	0.87	1.09
2	0.96	0.87	1.09
5	0.92	0.87	1.09
10	0.89	0.88	1.10
20	0.85	0.88	1.10
50	0.82	0.88	1.09

Dependence of an instrument's response on the radiation spectrum is only one of the many considerations for the choice of a transfer instrument Other factors to be considered are, for instance, the accuracy requirements in the field of the instrument's application, the ease of instrument handling and reading, and the reproducibility, stability, and permanence of the instrument

CONCLUSION

NBS plans to develop services for calibrating suitable measuring instruments in terms of absorbed dose in low-atomic-number materials, for use with electrons and photons in the energy range from approximately 1 to 50 mev. As the standard instrument, it is planned to use a graphite calorimeter surrounded by a graphite block For use in routine calibrations, a stable transfer instrument will be dev[illegible]

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§See, for instance, the paper by M J Berger and S M Seltzer—Calculation of Energy [illegible] Charge Deposition and of the Electron Flux in a Water Medium Bombarded with 20-[illegible] Electrons- in this monograph.

oped that requires less exacting measurements than does the calorimeter. Recommendations will be made concerning the users' laboratory instrument, to be calibrated against the NBS standard.

Since the absorbed-dose calibration services based on calorimetry will not be available immediately, an interim program has been initiated for uniformity checks of the high-energy electron-beam calibrations, using mailed ferrous-sulfate dosimeters

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