NIST Accelerator Facilities And Programs In Support Of Industrial Radiation Research

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Abstract. NIST’s Ionizing Radiation Division maintains and operates three electron accelerators used in a number of applications including waste treatment and sterilization, radiation hardness testing, detector calibrations and materials modification studies. These facilities serve a large number of governmental, academic and industrial users as well as an active intramural research program. They include a 500 kV cascaded-rectifier accelerator, a 2.5 MV electron Van de Graaff accelerator and a 7 to 32 MeV electron linac, supplying beams ranging in energy from a few keV up to 32 MeV. In response to the recent anthrax incident, NIST along with the US Postal Service and the Armed Forces Radiobiology Research Institute (AFRRI) are working to develop protocols and testing procedures for the USPS mail sanitization program. NIST facilities and personnel are being employed in a series of quality-assurance measurements for both electron- and photon-beam sanitization. These include computational modeling, dose verification and VOC (volatile organic compounds) testing using megavoltage electron and photon sources.

INTRODUCTION

The NIST has had a long and productive history in the field of radiation research. In the last half-century, NIST accelerator facilities have played a prominent role in much of this work, leading to the development of guidelines and standards for the industrial and medical communities. NIST’s program in accelerator research began to take shape in 1949 with the acquisition and installation of a 50 MeV and a 100 MeV betatron accelerator at the former NBS (National Bureau of Standards) site in Washington, DC. These machines helped to foster a new era of basic and applied research using high-energy electrons and photons at NBS. Meanwhile fundamental studies of low-energy electron and photon processes were being conducted using a 500 kV cascaded-rectifier accelerator. These measurements helped lay the groundwork for the development of radiation transport modeling and radiation dosimetry. When the NBS was moved to its present location in Gaithersburg, MD, three new accelerators were installed at this site as well as many of the original NBS radiation sources. These new sources included a high-power 100 MeV linac, a 2 MeV dynamitron and a 4 MV electron Van de Graaff. Of these sources, both the 500 kV cascaded-rectifier and the 4 MV Van de Graaff accelerator remain in use today. In 1992, NIST added to its complement of accelerators a 7 to 32 MeV medical linac donated by Yale New Haven Hospital. Originally equipped with a single therapy beam line, the machine has been upgraded to include a high-flux zero-degree port and a high-energy computed tomography beam line. These modifications have expanded the capabilities of the accelerator as a research tool. The Medical Industrial Radiation Facility (MIRF) continues to support a wide variety of industrial, medical and radiobiological research programs.

FACILITY DETAILS

The 500 kV electron accelerator consists of a vertical stack of oil-insulated rectifiers, air-insulated high-voltage terminal and evacuated acceleration tube. Beam energies are continuously variable from a few
keV to around 400 keV, with beam intensities ranging from a few pA to approximately 100 µA. A vacuum chamber coupled to the vertical beam line allows for scattering studies, evacuated detector calibrations and low-energy dosimetry measurements. A vertical beam port mounted to the bottom of the chamber allows the beam to be delivered to the room for in-air irradiation studies.

The Van de Graaff accelerator is an electrostatic, direct-current machine containing a vertical generator column and charging belt, high-voltage terminal dome and evacuated acceleration tube. The entire high-voltage system is encased in a steel vessel, electrically insulated by a high-pressure mixture of nitrogen and CO₂ gas. It delivers electron beams ranging in energy from around 500 keV to 2.5 MeV, or bremsstrahlung x-ray beams through the use of suitable targets. Beam intensities range from a few pA to around 100 µA. At present, three beam lines are in operation: a vertical beam port, used for high-dose irradiations, and two horizontal beam ports, used primarily for detector calibrations.

The Medical and Industrial Radiation Facility (MIRF) is centered around a 7 to 32 MeV traveling-wave linear accelerator (linac) donated to NIST by the Yale New Haven Radiation Oncology Center. Prior to installation at NIST, this accelerator was utilized at Yale for about 15 years in the electron and photon treatment of tumors. Constructed by the French firm CGR as a Sagittaire Model 32, it is estimated that between 5 and 10 thousand patients were treated with this accelerator during its tenure at Yale. This accelerator has been upgraded from its original configuration, including conversion to 60 cycle (120 beam pulses per second) operation and installation of several additional beam ports. The standard treatment head provides electron and photon fields from 2x2 cm to 36x36 cm, with dose rates from 1 to 5 Gy/min, a high-flux electron beam port with dose rates up to 10 kGy/min, and a high-energy computed tomography beam line currently under construction. Electron beam intensities delivered through the high-flux port range from a few nA to tens of microamps. An overview of the MIRF facility is given in Figure 1.

Table 1. summarizes the accelerator parameters and beam characteristics for these three accelerator facilities.

![FIGURE 1. Overview of the NIST Medical and Industrial Radiation Facility.](image)
<table>
<thead>
<tr>
<th>Accelerator Facility</th>
<th>Pulse Mode</th>
<th>Beam Energy Range</th>
<th>Beam Intensities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascaded Rectifier</td>
<td>Direct Current</td>
<td>A few keV to ~400 keV</td>
<td>pA to ~100 µA</td>
</tr>
<tr>
<td>Van de Graaff Accelerator</td>
<td>Direct Current</td>
<td>0.5 MeV to 2.5 MeV</td>
<td>pA to ~100 µA</td>
</tr>
<tr>
<td>MIRF Linear Accelerator</td>
<td>Pulsed (120 pps)</td>
<td>7 MeV to 32 MeV</td>
<td>nA to 10-20 µA</td>
</tr>
</tbody>
</table>

**NIST ACCELERATOR APPLICATIONS**

**Overview**

NIST accelerator facilities continue to support a broad range of applications including accelerator and radiation physics, and radiation dosimetry. They serve a wide and varied community of governmental, academic and industrial users. The broad range of energies covered and their accessibility makes these facilities particularly attractive to the user community. In addition to outside users, NIST accelerator facilities also foster an active program of intramural research. Details of some of these research efforts are given in the following sections.

**Radiation Hardness Testing**

Extensive studies to determine radiation damage effects in solar cells have been conducted using electrons from the Van de Graaff accelerator. Investigators from the Naval Research Laboratory are attempting to characterize radiation damage, as determined by a degradation in performance, using an approach based on a non-ionizing energy loss formalism. These studies were conducted at several energies and fluences to determine sensitivity to these quantities. In order to accommodate multiple cells simultaneously and eliminate the need for charge normalization, a turntable system complete with onboard Faraday cup was used. In this way, the cells pass through the beam in a continuous fashion and the Faraday cup registers the same electron fluence as the samples.

Several additional radiation hardness studies have been conducted including a set of measurements to characterize the performance of diodes to be used in commercial radiation dose monitors. Several hundred diodes were arranged on a reel and irradiated simultaneously to prescribed doses using 13 MeV electrons from the MIRF accelerator. Field uniformity across the sample area was achieved by using an aluminum beam flattener mounted to the accelerator vacuum window.

**Materials Modification Studies**

The Van de Graaff accelerator has been employed in several radiation modification studies of polymeric materials led by university researchers. In these studies, thin films of the copolymer Poly(vinylidenefluoride-trifluoroethylene) are irradiated at elevated temperature to alter their electromechanical properties. 1.2 MeV electrons are used to irradiate samples to doses approaching 1 MGy, at temperatures of around 100°C. This combination of dose and temperature produces a large electromechanical response in the material, making it suitable for use in a wide variety of actuator devices. For example, the electrostrictive strain response can be increased by a factor of 1000 under electron-beam irradiation. Work is currently underway to produce a prototype sonar transducer for the U.S. Navy employing these copolymer films.

**Environmental Applications**

Several sanitization studies involving high-energy electrons have been conducted using the MIRF accelerator facility. One such study involving researchers at the University of Maryland investigated the treatment of wastewater using 16 MeV electron beams. This experiment investigated the precipitation of heavy metals and the chemical deactivation of polychlorinated biphenyls (PCB’s) with the aid of high-energy electron beams. These experiments demonstrated that low to moderate radiation doses can be used effectively to remove mercury and lead metals from aqueous solutions.

An additional study, led by researchers from Northwestern University, dealt with the radiolytic...
degradation of dioxins in artificially contaminated soils. In these experiments, vials of soil were contaminated with dioxin containing compounds and irradiated with 10 MeV electrons at doses up to 800 kGy. These techniques proved to be highly effective in reducing the concentration of these toxins in contaminated soil.

**Mail Irradiation**

In response to the recent anthrax incidents, the NIST Ionizing Radiation Division, in cooperation with the United States Postal Service and the Armed Forces Radiobiology Research Institute (AFRRI), began a program to study the effectiveness of using radiation to sanitize the U.S. mail. These efforts involved computational modeling, validated by product dose mapping, to determine optimal processing parameters. NIST researchers, working with commercial processing firms, have developed elaborate phantoms and testing procedures for electron and photon beam sanitization of all types of mail including letters, periodicals and parcels. This work will help to provide quality assurance and a more consistent dose delivery to the product. Figure 2 shows calculated dose deposition curves in comparison with measured values for a typical two-sided electron irradiation of homogeneous product. This figure illustrates the effectiveness of two-sided irradiation in reducing the dose gradient and also the utility of computational modeling in defining radiation-processing parameters.

In an effort to assess possible hazards associated with irradiated mail, NIST along with AFRRI, conducted a series of experiments to study the formation of volatile organic compounds during the sanitization process. Several samples comprised of typical mail constituents were irradiated with high-energy electrons from the MIRF accelerator. These samples are being analyzed to determine the types of compounds produced, their yield and decay lifetimes. In this way, the exposure risk can be quantified, and measures may be taken to help mitigate these effects during processing.

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**REFERENCES**


