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\newcommand{\etal}[0]{{\em et al}}
\newcommand{\bibform}[5]{#1, {\em #2} {\bf #3}, (#4) #5.}
\newcommand{\japjap}[0]{Jap.\ J.\ Appl.\ Phys.}
\newcommand{\atdat}[0]{At.\ Data Nuc.\ Data Tables\/}
\newcommand{\statb}[0]{Phys.\ Stat.\ Sol.\ B\/}
\newcommand{\physd}[0]{J.\ Phys.\ D\/}



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\nopagenumbers
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\vsize=9.8truecm
\noindent\line{\hbox{\hskip 0.2truecm}\hfil\bf Monte Carlo Calculation of X-ray Spectra
Emitted by\hfil}
\noindent\line{\hbox{\hskip 0.2truecm}\hfil\bf Various Anode Materials at Low Voltages\h
fil}
\noindent\line{\hbox{\hskip 0.2truecm}\hfil Scott J.~Wilderman$^{1}$, Sean M.~Hames$^{1,
2}$, Michael J.~Flynn$^{2}$, and William R.~Martin${^1}$,\hfil}
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higan\hfil
}
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\hfil}
\bigskip
\noindent


Calculations of the absolute intensity and energy spectra
of x-rays emitted by various targets have
been performed for tube potentials in the 30-70 kV range
using a single scattering Monte Carlo method.
Monte Carlo modeling provides an accurate, practical method for
obtaining x-ray spectra from arbitrary target materials for which
experimental or semi-empirical results are not available.
The current Monte Carlo program, SKEPTIC (Simulated
Kilovolt Electron and Photon Transport In Condensed media),
utilizes fast sampling schemes and employs extensive
variance reduction techniques in order to reduce run time
inefficiences normally associated with single scattering electron
transport simulations.  Cross section data in the SKEPTIC
physics model is taken from the partial wave elastic scattering
formulation of Riley \cite{Riley75}, the doubly differential
bremsstrahlung description due to Pratt et al \cite1{Pratt77}. and the inner
shell ionization data from the LLNL Evaluated
Electron Data Library \cite{Perkins91}.  Calculated spectra and intensities
have been compared to available experimental data and semi-empirical
formulas.
Additional comparisons have been made with
quantitative measurements of the output x-ray spectra from a
microfocus source.
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\vskip 2truein
\line{Please direct correspondence to:\hfill}
\line{Scott J. Wilderman\hfill}
\line{Department of Nuclear Engineering\hfill}
\line{University of Michigan\hfill}
\line{Cooley Laboratory\hfill}
\line{Ann Arbor, Michigan  48109\hfill}
\line{(313)764-5290\hfill}
\line{email: sjw\_nc@engin.umich.edu\hfill}
\vfill\eject
\baselineskip=15pt
\noindent\centerline{\bf Monte Carlo Calculation of X-ray Spectra}
\noindent\centerline{\bf Emitted by Various Anode Materials at Low Voltages}
\smallskip
\noindent\centerline{Scott J.~Wilderman$^{1}$, Sean M.~Hames$^{1,2}$, and Michael J.~Flyn
n$^{2}$}
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\bigskip

\noindent{\bf Introduction}\smallskip

The
experimental spectra are unfolded to yield the absolute intensities.
Measurements have been made with a 7mm x 7mm cooled silicon
detector (AMPTEK XR-100) at various tube currents.

Detailed knowledge of the shapes of incident x-ray spectra is required for the
calculation and prediction of many important quantities in medical imaging
including the dose delivered in a radiologic
procedure,
the constrast expected between various structures in an image, and the general
performance and response characteristics of detection devices.  This is especially
true for low anode voltages,
in which case a substantial fraction of the photons lie near energies of the
of the peaks in the photo-electric aborption cross sections, and shifts
in x-ray spectra of just a few kilovolts can have
large impacts on feature contrast and detector response.

Even at higher energy,
because of the large number of factors influencing the
generation and eventual emission of x-rays, analytic models of x-ray spectra
emitted by thick targets upon electron bombardment are crude and approximate,
limited to semi-empirical descriptions.
Typically, production of characteristic
photons in these approaches is decoupled from the model of bremsstrahlung
yield, and available only in parameterized form for specific applications
using standard materials.  At present, there exist no platforms
capable of modeling
output either at low anode voltage or from non-uniform
targets, such as found in dual focal spot mammography tubes.

\noindent{\bf Methods}\smallskip

Until recently, the problem
of spectrum determination has also
defied solution by the more rigorous Monte Carlo method, because of both
the high price in computing time and because of the lack of a good model of
electron transport at low energies.  The enormous number of collisions
seen in the trajectory of each particle has required that an approximate
condensed random walk approach, in which particles are transported through
hundreds or thousands of collisions in one large step, be applied.
Even with detailed refinements designed
specifically to address accuracy problems generated
by using this technique \cite{Beil86}, problems still
exist in modeling electron transport in the range of a few
tens of keV, especially for high Z materials \cite{Beil86,Wild90}.

Researchers have long been exploring the
possibility of using Monte Carlo simulation of electron transport in a full
analog treatment of the random walk \cite{\Murat71,Shim76,Akker80}.
Obviously, analysis of individual collisions is incredibly time consuming,
and most single scattering programs have been limited to very low
initial energies and high variance (because of the small number of
histories available.
Recent advances in computing capabilities, however, have reduced
run times to the point where the simulation of such low probability
phenomena as x-ray production in thick targets with this method is now
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possible.  Using highly accurate cross section
data \cite{Riley75,Pratt77,Perkins91}, extensive variance reduction,
and a fully vectorized Monte
Carlo algorith, adapted spefically for implementation on a Cray YMP
computer, we have developed a platform for tracking electrons on
an event by event basis which is fast enough to yield differential
spectrum data in a reasonable time frame.
In the this paper we present a comparison of experimental data with
results of spectra generated by our approach.

\noindent{\bf Results}\smallskip

Some preliminary results are presented here.

The first experiment modeled was the yield of x-rays from a
thick chromium target bombarded by
monoenergetic electrons from  Lifshin \etal.\ \cite{Lifshin77}.
Results are present in table \ref{class_I_1}

\begin{table}
\begin{center}
\begin{tabular}{|c|c|c|}
\hline
Energy (keV)  &  Experiment  &    Calculation   \\ \hline
10            &    .403      &     .458         \\ \hline
15            &    1.38      &     1.58         \\ \hline
20            &    2.69      &     2.70          \\ \hline
25            &    4.29      &     4.10           \\ \hline
\end{tabular}
\end{center}
(Values in $10^{-4}$ photons/electron-steradian)
\caption{Absolute X-ray Yield for 10 -- 25 keV Electrons on Chromium}
\label{class_I_1}
\end{table}


\noindent{\bf References}\smallskip
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