LA-UR- 09-03184

Approved for public release; distribution is unlimited.

Title: Charged Particle Energy Loss Radiography for Homeland Security Applications

Author(s): K. N. Borozdin, C. Morris, A. M. Fraser, J. A. Green, F. G. Mariam, L. J. Schultz, L. Cuellar, N. W. Hengartner, A. Saunders, P. L. Walstrom
Los Alamos National Laboratory, Los Alamos, NM, U.S.A

Intended for: 2009 IEEE Nuclear Science Symposium and Medical Imaging Conference, October 25 – 31, 2009, Orlando, Florida

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (7/06)

Abstract #2274

Charged Particle Energy Loss Radiography for Homeland Security Applications

K. N. Borozdin, C. Morris, A. M. Fraser, J. A. Green, F. G. Mariam, L. J. Schultz, L. Cuellar, N. W. Hengartner, A. Saunders, P. L. Walstrom

Los Alamos National Laboratory, Los Alamos, NM, U.S.A.

We discuss an innovative low-dose approach for detecting shielded SNM based on measuring the energy-loss of energetic protons penetrating an object. Detection of nuclear weapons and special nuclear material is crucial to thwarting nuclear proliferation and terrorism and to securing weapons and materials worldwide. Unfortunately, existing and even emerging techniques of detecting shielded SNM all have significant drawbacks and do not solve the problem[1]. The required technology must be fast, efficient and safe. Here we present a novel approach that satisfies all those requirements. Our method is fast, because the required beam currents are at the picoAmpere level (millions of times below currents achievable in accelerators), enabling rapid scanning of moving objects. It is efficient because energetic protons are highly penetrating (up to half of a meter of solid iron for 800 MeV protons), and energy loss measurements are very informative about the materials transversed. Because just a few particles are needed to assess a volume, the method is safe, utilizing doses of radiation at the microrem level, well below those of routine air travel.

Our approach is based on information provided by the energy loss of energetic protons in different materials. For mono-energetic particles, energy loss depends mainly on the amount of material (or density multiplied by the material thickness) along the tracks, though it is also a function of atomic number Z. The probability density function for energy loss is described by a narrowly peaked Landau-Vavilov distribution, therefore each single particle provides a good measurement of the amount of material it penetrated. A few particles are enough to measure material parameters with high precision, providing for high-quality radiography with extremely low dose. Even a single-projection energy-loss-only radiography would be qualitatively superior to existing technologies based on attenuation of high-energy photons (X-ray radiography[2], CAARS[1]). We can however further improve the performance by using multiple beam projections for 3d tomographic imaging and/or by incorporating signals from the multiple Coulomb scattering and nuclear attenuation of the beam. In previous work we demonstrated how to use the multiple scattering of a tomographic charged particle flux for improved nuclear threat detection and 3d reconstruction[3]. Now we propose to go beyond multiple scattering and use new and superior information source, energy loss measurements, for even better separation between different materials with fewer particles needed to irradiate the object.

---

[1] Medalia, J. Detection of Nuclear Weapons and Materials: Science, Technologies, Observations, CRS Report for Congress, **R40154**, Nov 6, 2008

[2] Katz, J. I., Blanpeid, G. S., Borozdin, K. N. and Morris, C., *X-Radiography of Cargo Containers*, Science & Global Security, **15**, 1: 49, 2007

[3] Borozdin, K.N., Hogan, G.E., Morris, C., Priedhorsky, W. C., Saunders, A., Schultz, L. J., Teasdale, M. E., *Radiographic imaging with cosmic ray muons*, Nature, **422**, 277, 2003

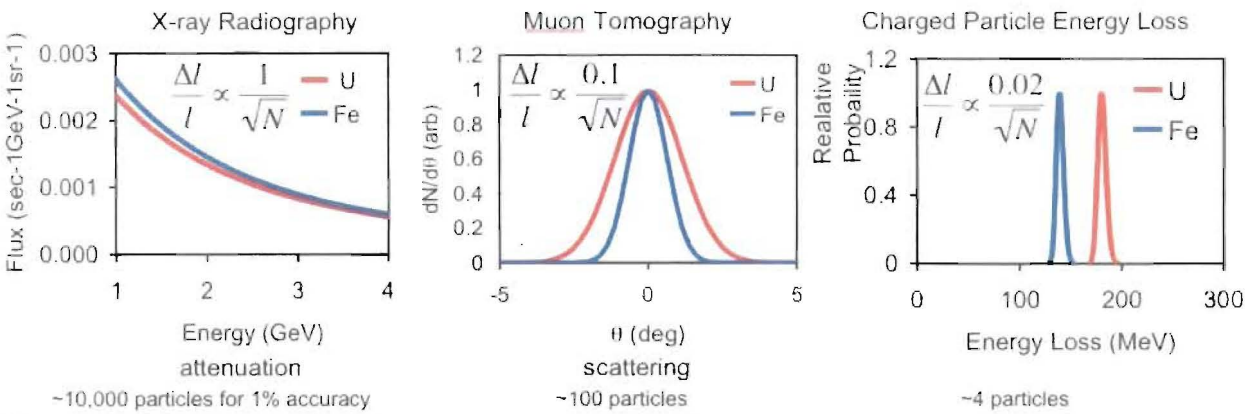

Figure 1. Comparison of the information content for different radiographic measurements. Sample curves are made for 10 cm thickness of uranium and iron.

Experimental demonstration of our approach is not a trivial task. First, it requires a source of high-energy protons with energies of several hundred MeV. We can demonstrate our technology using the existing 800 MeV proton beam at Los Alamos (LANSCE), an ideal energy for radiography of a wide range of objects. Future applications will require more compact and cheaper sources, and development of such accelerators is an active and exciting area of research. The ongoing collaboration of MIT and Los Alamos scientists with the Raytheon Corporation intends to build within the next few years a 500 MeV superconducting compact proton cyclotron with a diameter of about 2 m and cost about $3M in production. Such an accelerator would be an adequate source of protons for the applications we have considered. If necessary, protons can be boosted by superconducting cavities, another cutting-edge technology under active development at Los Alamos.

We propose to measure the energy loss of transmitted protons with a magnetic spectrometer consisting of two planes of position-sensitive drift chambers to measure protons angle of deflection, and thus their momentum, in a dipole magnetic field. According to our simulations, we can detect SNM threats hidden inside innocuous objects with extremely low dose irradiation. For experiments and demonstrations we need a strong electromagnet able to generate required $BL \cong 1T \cdot m$ magnetic field and position-sensitive drift chambers with sub-mm resolution in two dimensions. Such position-sensitive detector system will be able to measure trajectories of individual protons in a low-intensity fan beam, and enable measurements of not only their energy loss, but also the amount of multiple scattering along each track. This is an important secondary signal, because scattering is a much stronger function of Z-number of the material than energy loss. Therefore, we can measure independently not only the density, but also the atomic number of materials for improved separation of materials within one group (for example, we would be able not only to distinguish between uranium and iron, but also between uranium and lead). The accuracy of the material characterization will be further improved by applying advanced reconstruction methods that take into account different physical models of the processes under consideration.

Detection geometry can be modified as required for a particular application. Out method is ideal for moving objects, allowing to scan them at the speed of their natural movement with mobile or stationary system. In future applications, the scanning can be made both at chokepoints or using mobile platforms, such as boats, planes or vehicles.