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Bubble Masks for Time-Encoded Imaging of Fast Neutrons
165680

Year 1 of 1
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Project Purpose:
Fission-energy neutrons are an important signature of the special nuclear material (SNM) used in nuclear explosives, and high-resolution neutron imaging systems are desired for applications such as arms control treaty verification and emergency response. The time-encoded imaging technique produces images by inducing a time-dependent modulation of detected neutrons, and is characterized by simple and robust detector elements, low channel counts, and low cost, in contrast with other imaging approaches. However, time-encoded imaging of fast neutrons has never been demonstrated in a high-resolution mode needed for these applications. There are significant conceptual and engineering challenges in building a large high-resolution mask of bulky hydrogenous material, moving in a complex controlled fashion to produce the desired time-dependent attenuation patterns. We aim to enable high-resolution time-encoded imaging using the approach of bubble masks, in which arbitrary time-dependent neutron attenuation masks are formed by bubbles propagating through a viscous medium such as mineral oil.

DOE NNSA NA-22 is currently funding a project to develop time-encoded neutron imaging, and the bubble mask concept has arisen out of that work. But although the potential payoff is significant, the risks are also too extensive to justify pursuing the idea within the scope of the NA-22 project. Bubbles can be simply introduced into an oil column using a valve at the base of a tubing element. However, the feasibility of tuning the oil viscosity and the characteristics of the tubing (size, shape, pressure relief, etc.) to make the bubble propagation consistent and predictable is unknown. The speed of the bubble motion may depend on the spacing of other nearby bubbles via pressure and wall effects, for example, making it difficult to generate a moving mask with precise element spacing, such as the family of uniformly redundant arrays that have attractive imaging properties. If successful, the bubble mask technique would enable robust high-resolution imaging of SNM at low cost.

Summary of Accomplishments:
The goal of this one-year project was to determine the feasibility of building bubble masks for neutron time-encoded imaging, and identify any limitations on their design or performance. We have successfully demonstrated controlled introduction and propagation of bubbles through a tube of viscous hydrogenous liquid in a pattern relevant for time-encoded imaging of fast neutrons. We developed a technique for tracking bubble positions in real time and methods to reconstruct a source distribution from acquired neutron rate data. Results from a simple experimental setup provide a demonstration of the concept, and give us confidence in simulation results. The simulation was then used to extrapolate beyond the experimental results to explore the potential performance of a large-scale imaging system based on bubble masks.

Two major limitations of the bubble mask technique were identified. The first is the challenge of achieving a high mask contrast, which would require tubes (and therefore bubbles) with large cross-sectional area, and ideally a rectangular shape. The second is the inherent correlations among the response vectors of nearby source positions, due to the motion of the bubbles through the tubes. Low mask contrast and non-ideal orthogonality

both contribute to slower resolving times, or the need for more statistics for a given detection threshold or image resolution.

Advantages of the bubble mask technique include the length of the encoding pattern, which is limited only by the length of the acquisition, in contrast to fixed moving masks, which must be cyclical with some finite length. In addition, the ability to respond to observations by changing the mask pattern (adaptive encoding) has potential to improve resolving times and open up a new class of algorithms for source detection and imaging.

Significance:

We accomplished what we set out to do in this small-scale project, which is to lay the technical groundwork for using bubble masks to enable two-dimensional time-encoded imaging. Since their feasibility has been demonstrated, bubble masks could be developed for applications in which ease of deployment is key (e.g. radiological emergency response). We identified what technical issues should be addressed next (e.g. increasing tube/bubble size), and developed related technical concepts that might be more optimal for some of the application space. Some of our work on adaptive encoding will apply broadly to other imaging modalities.

Refereed Communications: