# R3-D: Magnetic Resonance Based Detection of Illicit Materials

**Abstract— Imagine, you have to quickly figure out just what liquid is inside a bottle. The container might be opaque, or even metal. You can't open it, and you can't trust what is on the label. That scenario is faced in airports, at border crossings and by first responders to hazardous- material or bomb scares. Moreover, the need to accurately identify liquids is common in quality control of everything from medicine to cosmetics to foods.**

**By combining nuclear magnetic resonance (NMR) and X-ray imaging, scientists can meet the challenge of liquid identification more reliably than with either technique alone.**

## I. PARTICIPANTS

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## II. RESEARCH ACTIVITY

### *A. Project description*

Magnetic resonance imaging (MRI) is the premier noninvasive diagnostic for imaging soft tissue, in which changes in density are subtle. It works because, unlike density differences, chemical differences within the tissue are significant enough to strongly influence the NMR signal that is the basis of MRI. When applied to obtain high-resolution images of anatomy, MRI requires large magnetic fields and expensive equipment. But it is possible to perform MRI with much weaker fields, if high resolution is not needed. From early on in NMR history, groups have demonstrated the technique in fields as low as that of Earth. For liquid screening, we at Los Alamos National Laboratory "pre-polarize" the sample with a field of about 50 mT, 1000 times Earth's magnetic field. We can then read out the precession of the magnetization with a field comparable to that of Earth. The low-frequency signal associated with such a weak read-out field can penetrate through metal. The weak fields are safe for the security checkpoint setting, as metal is not moved or heated, and as a bonus, the expense of field generation is greatly reduced.

If you've seen X-ray images in a doctor's office, you know that X-rays behave differently as they pass through various materials. Denser or thicker materials like bones stand out in X-ray images because they absorb a relatively large fraction of the X-ray intensity that strikes them. Obtaining a complete understanding of X-ray attenuation is a very complex undertaking, but some key general concepts are simply stated. First, attenuation depends on the energy of the X-ray beam; higher-energy beams generally attenuate less. Second, attenuation is linearly dependent on the density of the material; twice as many molecules of a material stop twice as many X-rays. Third, attenuation is nonlinearly dependent on the atomic number of the material; at typical X-ray energies, materials with higher atomic number stop more X-rays.

For a given material of specified thickness, analysis of an X-ray image will yield attenuation for the energy of the X-ray beam. If the identity of the material is unknown, one could try to find out what it is by comparing it against a library of attenuation values from known materials. Since specimen and library values depend on X-ray energy, running the comparison at two or more different energies will reduce the uncertainty in the characterization of the unknown material

An NMR signal is typically generated by hydrogen atoms because it is those atoms that readily respond to magnetic fields—that is, the more hydrogen atoms, the stronger the NMR signal. In security applications, for example, many benign liquids are water based, and exhibit a characteristic NMR signal.

On the other hand, many explosive liquids are packed with additional elements, so the density of hydrogen atoms goes down significantly. For those liquids, the NMR response is less than for water. Other types of explosive liquids have excess hydrogen atoms and provide an NMR response greater than for water.

The NMR signal is also affected by the volume of liquid in a bottle – twice the volume generates twice the signal. X-ray analysis can determine the volume of liquid, therefore, bringing together X-ray and NMR techniques enables the volume effect to be removed in determining the hydrogen content of a liquid.

Indeed, the benign and threat regions of the space established by NMR and X-ray inspection of a liquid are well separated; as a result, in airport-security applications both false alarms and missed detections of dangerous materials should be less than they would be if NMR or X-ray were used individually. In addition to addressing security issues, which is a particularly difficult application, the combined NMR and X-ray technology can answer such questions as: 1) Has food or medicine spoiled? 2) Does a liquid meet quality control standards? 3) Has a foreign chemical been added to water? 4) Is this expensive bottle of wine really as advertised? In all those cases, the nondestructive imaging combination shows the promise to be more reliable and less costly than destructive statistical sampling techniques currently in use.

Figure 1 is excerpted from "What's in that Bottle?" to appear as a Physics Today Quick Study article.

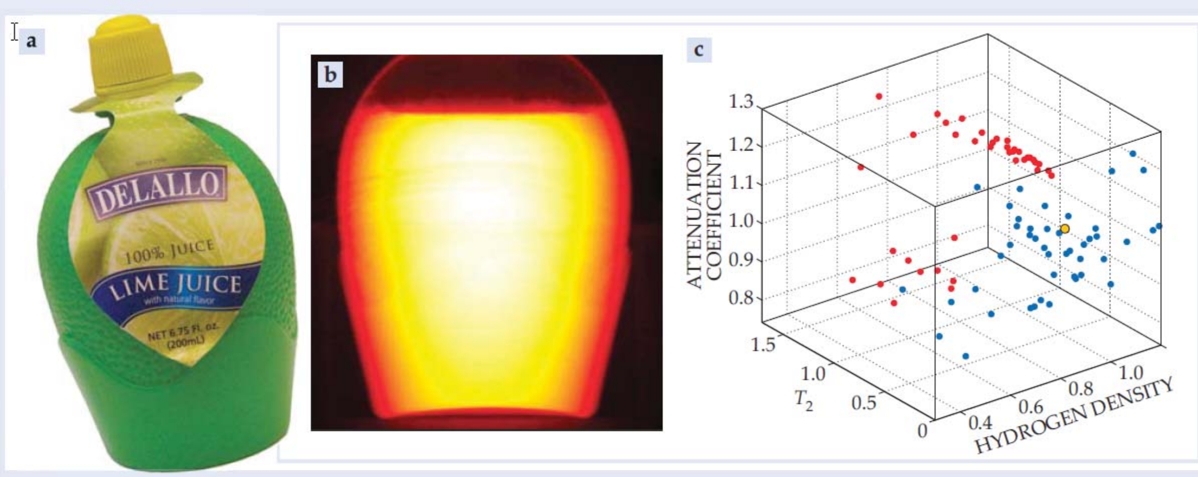


**Figure 2. It says lime juice**, but is it really? An off-the-shelf bottle of lime juice **(a)** generates an x-ray image, such as in **(b)**, from which we can extract the volume and attenuation coefficient of the liquid. In the x-ray image, the white areas are those of greatest attenuation; the orange areas are of less attenuation. **(c)** We combined x-ray data with nuclear magnetic resonance data to get a signature of the juice (yellow point) in a three-dimensional space. (The meaning of the relaxation time $T_2$ is explained in figure 1.) The result can be compared against a library of safe (blue) and dangerous (red) materials. Our prototype system classified the lime juice as a water mix. The three axis variables are given relative to the values for water.

**Figure 1: a) an off-the-shelf bottle of lime juice generates an X-ray image, such as in b) from which we can extract the volume and attenuation coefficient of the liquid, the white areas are those with the greatest attenuation; the orange areas are less. C) We combined X-ray data with nuclear magnetic resonance to get a signature of the juice (yellow point) in a three-dimensional space. The results can be compared against a library of safe (blue) and dangerous (red) materials.**

### *B. State-of-the-art and technical approach*

X-ray imaging, such as you may have seen in dental offices or an airport, is ubiquitous in the public domain. So is NMR, but not at the low fields necessary for practical liquid scanning. With support and guidance from the US Department of Homeland Security (DHS), we at Los Alamos have taken low-field NMR out of the laboratory and demonstrated that it can work in a public setting.

### *C. Major contributions*

Two NMR instruments (not combined with X-ray imagers) were tested at the Albuquerque airport in New Mexico. The first was an imaging machine that examined trays of bottled liquids (1). The second was a much more compact instrument for scanning individual bottles (2). Those exercises showed that low-field NMR machines could operate in the electronically cluttered public-transportation environment. Now, we've returned to the lab and are working to integrate safe X-ray machines and NMR instruments. A video record of the results of our prototyping can be found at http://www.youtube.com/watch?v=nizjDxt3F5Q.

Although NMR and X-ray imaging have been demonstrated individually in both public and industrial environments, the combined technology has not. Work still needs to be done to test materials, assess the influence of bottle shape and container material over the widest class of packaging and figure out how to merge the techniques for rapid and cost-effective screening of multiple bottles.

Time will tell whether combined NMR and X-ray screeners will appear in an airport near you, but already we have seen that the physics of two completely different imaging modalities can come together to provide new information for solving difficult problems.

## III. RELEVANCE AND TRANSITION

Through the ALERT center, discussions are now taking place between Los Alamos National Laboratory, Northeastern University and AS&E to determine the future potential for a commercial integrated NMR and X-ray device.

## IV. LEVERAGING OF RESOURCES

External funding from DHS will be pursued. ALERT Career Development Grant student, Michael Collins, worked on this project for his required 10-week summer internship.

## V. PROJECT DOCUMENTATION AND DELIVERABLES

### *A. Peer reviewed journal articles*

**Pending-**

1. Espy Michelle, Hunter James, Schultz Larry . "What's in that Bottle?" To appear in Physics Today

### *B. Other*

1. http://www.youtube.com/watch?v=nizjDxt3F5Q

## VI. REFERENCES

[1] http://www.youtube.com/watch?v=xT2zncrtU-s
[2] http://www.youtube.com/watch?v=HQT5iAwodDc