Shipping Anomaly from NMIS Imaging

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ABSTRACT
In 2007, a shipping container that arrived at ORNL was imaged using the neutron and gamma-ray imaging capability of the Nuclear Materials Identification System (NMIS). NMIS with imaging uses a time-tagged radiation source, which can be either a D-T neutron generator or a ^{252}Cf spontaneous fission source. The initial imaging measurements used the D-T generator's 14.1 MeV neutrons. Because of the low attenuation of the container and its contents, subsequent measurements were performed with the fission energy spectrum neutrons and gamma rays of the ^{252}Cf source. The ^{252}Cf source provides a simultaneous measurement of both a neutron (more sensitive to organics) and a gamma-ray (more sensitive to steels) image to be obtained. The images showed that the container contents were partially inverted instead of their expected arrangement. This information was useful in assessing the shipment packaging before the container was opened and indicates how NMIS with imaging can be used to image receipts.

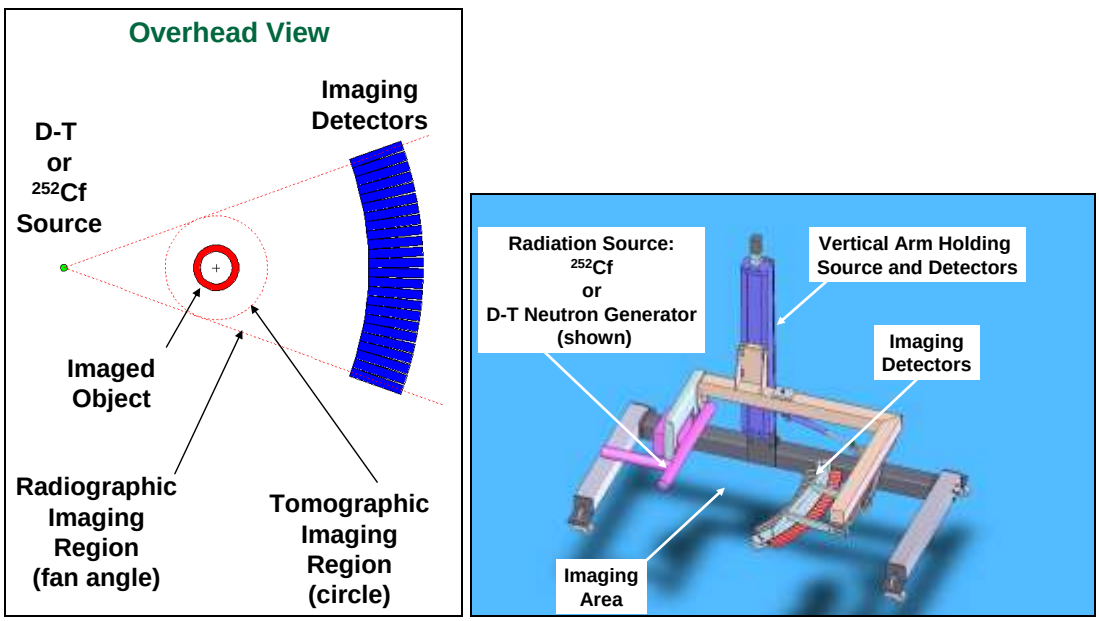
INTRODUCTION
From time to time there is a need to examine a hazardous shipment before opening the shipping container. This need is often met by radiography employing photons or neutrons. This paper describes a radiography measurement of such a container that employed both gamma rays and fast neutrons.

DESCRIPTION OF THE NUCLEAR MATERIALS IDENTIFICATION SYSTEM
The Nuclear Materials Identification System (NMIS) does radiographic and tomographic imaging, Rossi-alpha die away measurements, and multiplicity measurements [1,2]. Its imaging configuration consists of a time-tagged radiation source and a fan beam array of detectors on opposite sides the container to be imaged (see Fig. 1a). The source and detectors are mounted on the U-shaped arm of a scanner (see Fig.1b). This arm can move the source and detectors to make an image measurement at any elevation. The scanner can also move the fan beam detectors incrementally along their arc around the source in order to image with finer horizontal resolution.

NMIS's main purpose is to examine fissile materials, so its main radiation source is high-energy neutrons that can penetrate dense materials and induce fissions in the target object. However the system can employ a variety of sources and detectors. NMIS has imaged objects using 14 MeV neutrons from a D-T neutron generator, fission spectrum photons and neutrons from a ^{252}Cf source, and 1 MeV gamma rays from a ^{60}Co source. The system is designed to image at about 5 mm resolution however it can do better by measuring at finer spacing and using iterative image reconstruction techniques. The

measurements described in this paper use a ^{252}Cf source and a fan beam array consisting of 24 1×1×6 in. plastic scintillation detectors on an 85 cm radius arc around the ^{252}Cf source. The system's measurements are derived entirely from the time that events occur in the detectors. The ^{252}Cf fissions spontaneously and is embedded in a parallel plate ionization chamber that detects its fission fragments and thus time-tags the emission of the fission neutrons and gamma rays. The fan beam detectors time-tag the arrival of these particles. These times are acquired through a computer processor board that acquires these times with nanosecond resolution [3].

The system measures the time correlation [4] of these events and thus measures the transmission of the fission particles through a shipping container, coincident with their emission from the ^{252}Cf source. Because the measurement is based on time-coincidence with the interrogating radiation source, it can be performed on containers of radioactive materials without interference from the radiation coming from the container. The time-tagging also allows NMIS to separate the gamma-ray and neutron transmissions because their time of flight differs; hence, NMIS can produce a gamma-ray and neutron radiograph of an object with a single measurement.



(a) (b)

Fig.1. (a) NMIS produces a radiographic or tomographic image using a time-tagged radiation source on one side of the imaged container and a fan beam array of detectors on the other side. (b) The NMIS scanner holds the source and fan beam array on a U-shaped arm that positions them vertically. The scanner can also move the fan beam detectors incrementally along their arc around the source in order to sample with finer horizontal resolution.

CONTAINER MEASUREMENT

NMIS was employed to make radiographs of the container contents. The photographs in Fig. 2, taken before container shipment, show the shipping drum, an inner container, and packing foam used to hold the inner container in place. (The NMIS measurement team performed the measurements and analysis without any prior knowledge of the container contents.)

The initial NMIS radiographs of the container were made using a D-T neutron generator source. These radiographs had low image contrast, demonstrating that the container's contents were too transparent to the D-T generator's 14 MeV neutrons to produce a good image. Subsequent radiographs were made using a ^{252}Cf source. The ^{252}Cf source spontaneously fissions, producing gamma-rays and neutrons with a fission energy distribution that is less penetrating. The radiographs shown in this paper are the result of a detailed measurement. Image resolution is ~5 mm, the measurement time at each pixel is 128 seconds, and a 500,000-fissions-per-second ^{252}Cf source (~0.5 µ-grams) was used. The total measurement time was 10 hours because this configuration uses 24 detectors (measures 24 pixels at a time). The detectors' threshold was set at the equivalent of a 1 MeV neutron and a 0.2 MeV gamma ray.

Fig. 2. Photographs taken before container shipment show the inner container is standing upright and held in place by a foam ring.

The gamma-ray radiograph in Fig. 3 shows that the inner container, as received, is inverted with its heavy metal lid on the bottom. It is sitting at an angle, and there is no indication of what is supporting it. Three more containers can be seen inside it.

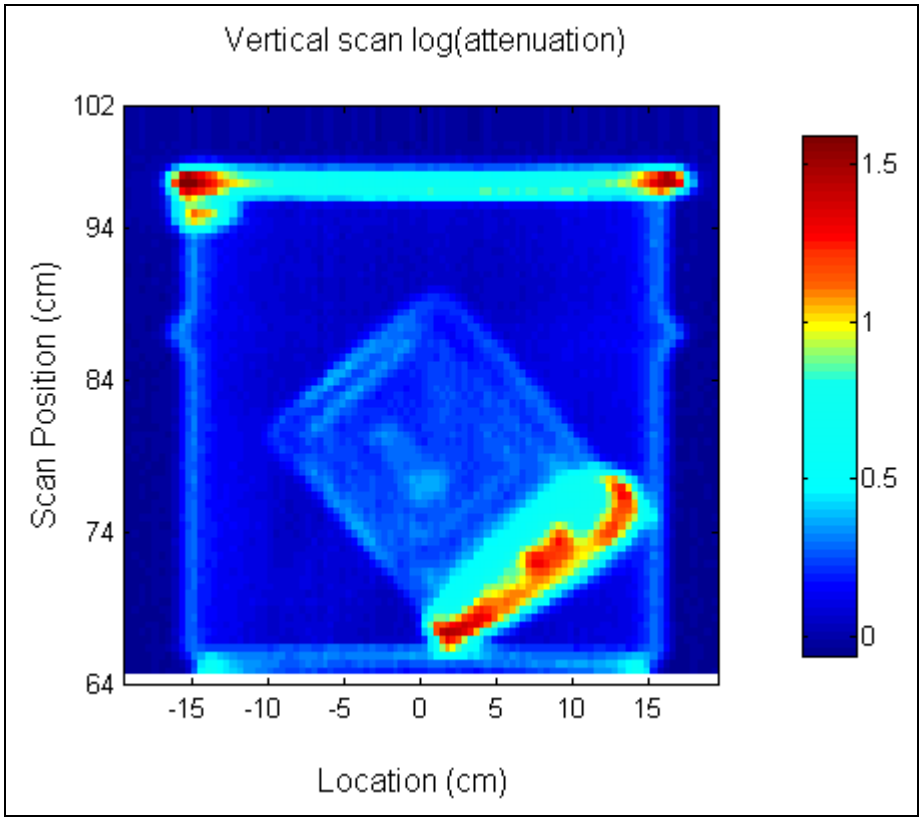


Fig. 3. The gamma-ray radiograph shows the inner container is inverted, and three more containers are inside it. *(Color reproduction for printed copies might not show the inner-most containers.)*

The neutron radiograph in Fig. 4 also shows the inverted inner container and its heavy metal lid. It is clear that the neutrons produce a coarser image. This occurs, at least in part, because the elastic scatter of neutrons tends to be in the forward direction. A neutron can be deflected into an adjacent detector, causing an apparent successful transmission for the wrong path through the object. Another contributing factor is that the colorization for this picture has been pushed to emphasize two low attenuation regions. The first is a ring around the inner container (aqua-colored region); the second is an aqua-colored region on the left between the inner container and the shipping drum wall. These do not appear in the gamma-ray radiograph, so high-Z materials are unlikely. The more likely explanation is that these are hydrogenous materials which neutrons are sensitive to because they can scatter neutrons at wide angles (away from the fan beam transmission detectors). The radiograph makes it clear that these materials are supporting the inner container. The neutrons also show two regions inside the inner container that the gamma rays did not show.

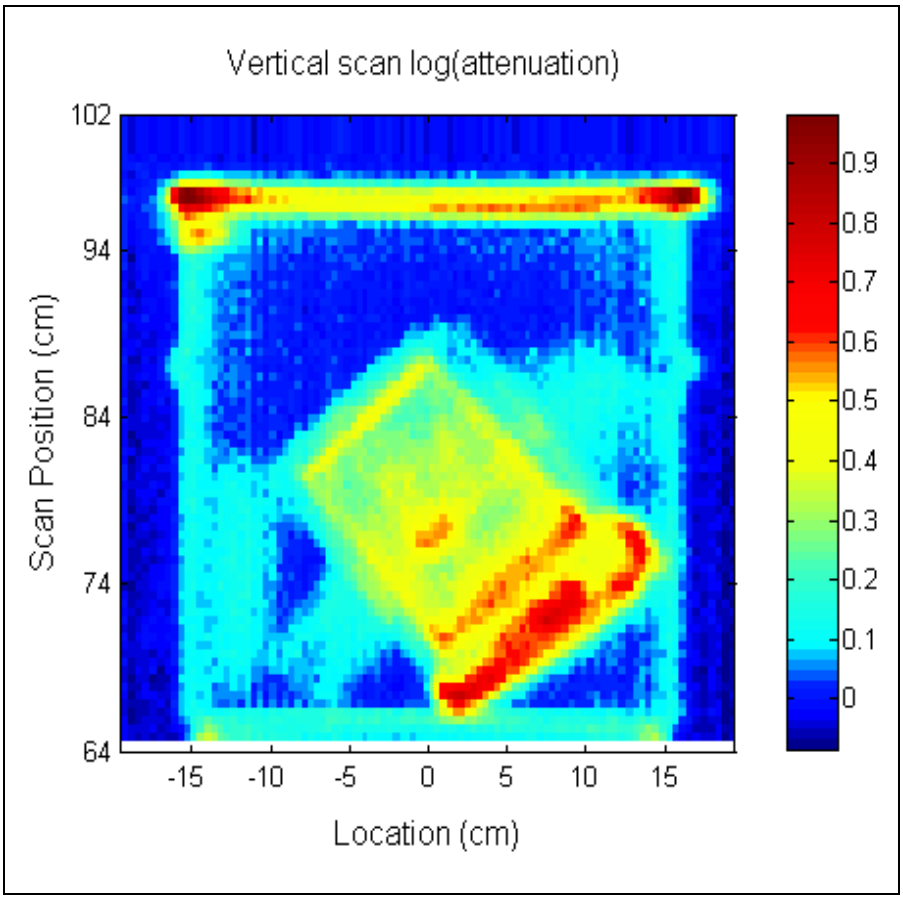


Fig 4. The neutron radiograph shows the dense metal areas but also materials not visible in the gamma-ray radiograph (the ring around the inner container, the slab on lower left, and two regions within the inner container).

Figure 5 shows the neutron radiograph and the shipping drum contents as received. The photograph shows that the materials around the inner container are packing foam. Its ability to detect hydrogenous materials (even the very-low-density foam which was supporting the inner container) makes this a useful imaging technique.

Fig.6 shows the gamma-ray radiograph and the set of nested inner containers. The radiograph shows the walls of each of the plastic and metal inner containers.

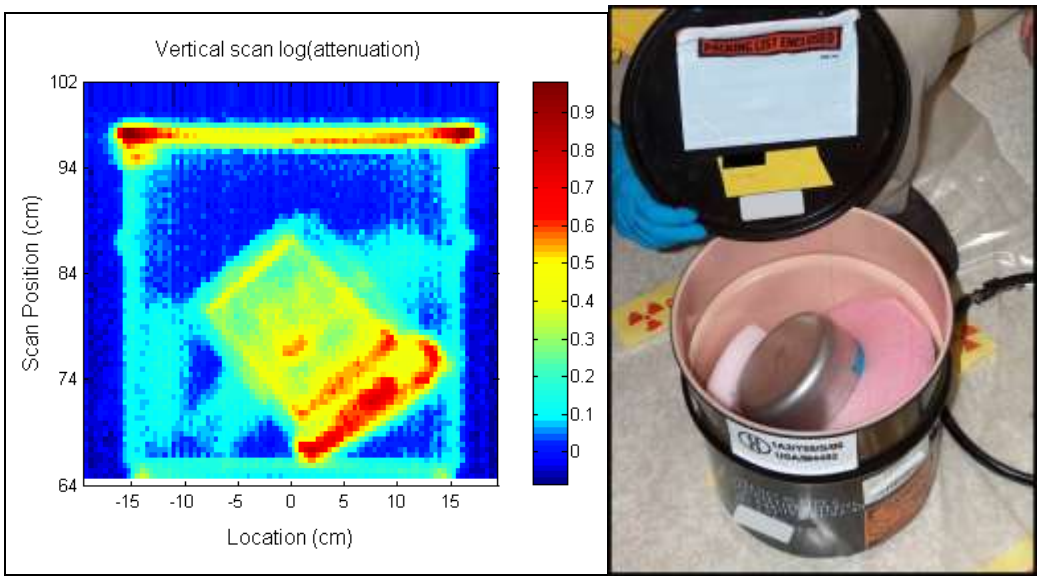


Fig 5. The neutron radiograph and a photograph of the inner container as received, showing that the neutron radiograph has detected the low-density packing foam.

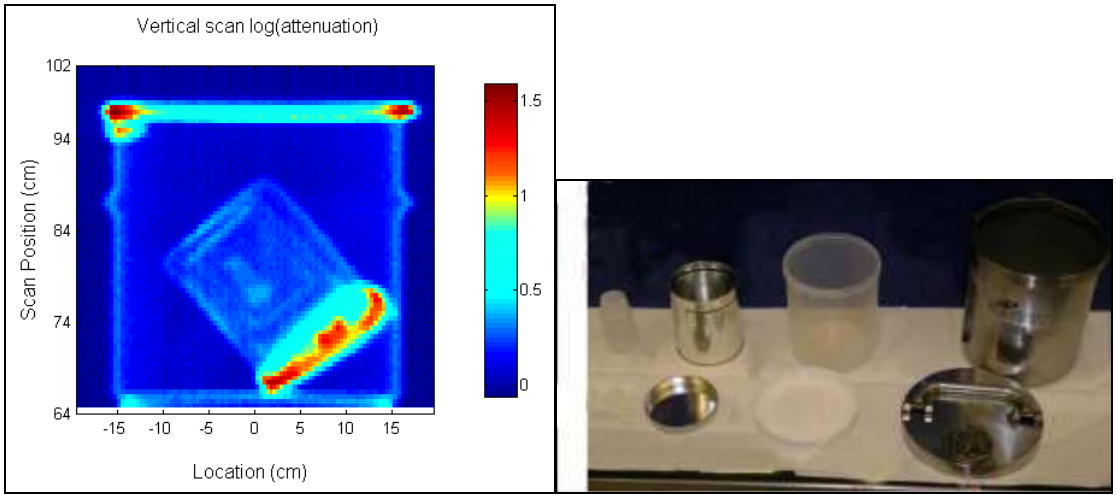


Fig 6. The gamma-ray radiograph and a photograph of the full collection of inner containers, showing that the gamma-ray radiograph has detected the inner containers. *(Color reproduction for printed copies might not show the inner-most containers in the radiograph.)*

CONCLUSIONS

Radiographic imaging using gamma rays and neutrons proved its usefulness by revealing the nested inner containers and the packing foam supporting the inner container. The neutron and gamma-ray images complement each other in that they are sensitive to different materials. Contrasting their differences helps to identify the materials.

The radiograph results gave enough information that the main components of the shipment could be deduced by visual inspection of the radiographs without the benefit of prior knowledge of the container contents.

REFERENCES

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