Fast Neutron and Gamma-Ray Interrogation of Air Cargo Containers

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Outline

- Scope of CRP Project
- Industry Requirements
- X-rays and neutrons
- Fast Neutron and Radiography Technique
- CSIRO Air Cargo Scanner at Brisbane International Airport
- Reference Scanner
- Current status
Scope of Project under IAEA Coordinated Research Project

Under the terms of the Research Agreement between the IAEA and CSIRO, the specific activities include:

- Evaluation of FNGR for the detection of contraband in consolidated air cargo

- Enhancement of FNGR technology as it relates to the examination of air cargo with a view to improved contraband detection and to reduce the incidence of false positives and false negatives.

- The assessment of neutron generator and detector systems for FNGR.
Air Cargo Inspection

Overall Objective: To efficiently find contraband (such as explosives, illicit drugs, illegal imports, weapons, nuclear materials) in air cargo

- Air cargo packed inside lightweight aluminium containers (ULDs) and on pallets.
- Large volume of air cargo (e.g. ~500 ULDs/day at Sydney airport) and time critical nature of cargo movement

Manual inspection: Time consuming and labour intensive (for unpacking, inspecting and repacking)

There is a critical need for improved cargo screening systems
Requirements for Air Cargo Screening System

- Distinguish broad range of contraband in air cargo containers
- Provide density, shape and composition images
- Scan consolidated cargo without unpacking
- Rapid scans (~2 minutes/container) and short turnaround time
- Minimum number of false indications
- Comply with strict radiation safety requirements for both operating staff and cargo irradiation
- Readily integrated with existing airport systems
- Reasonable capital and operating costs
X-ray & Gamma-ray Technologies

- High energy X-ray or gamma-ray radiography is the most commonly used screening technique
- Many commercial systems (fixed, mobile, LINAC, radioisotope sources)
- Provide high resolution images of shape and density
- Difficult to distinguish organic materials
- High operator skill required for complex, cluttered images
Main Advantage of Neutron Techniques
• Determine elemental composition not just density

Two Classes of Neutron Interrogation Techniques
• Radiography
• Secondary Radiation

For neutron techniques to be successful they must
• meet the industry requirements and
• have significant advantages over the established and developing X-ray and gamma-ray systems
Material Thicknesses for 0.1% Transmission of Neutrons, Gamma rays and X rays
CSIRO/Australian Customs Collaboration

- CSIRO Minerals first approached by Customs in December 2001
- CSIRO initiated a feasibility study: Stage 1 (Completed September 2002)
- Full scale demonstration of FNGR at CSIRO using consolidated ULDs with contraband: Stage 2 (Completed June 2003)
- Federal Government allocated $8.4 million to Australian Customs to construct and evaluate a commercial-scale CSIRO Air Cargo Scanner at Brisbane Airport: Stage 3 (Mar 2004 – February 2007)
- Reference scanner commissioned at CSIRO for trials, R&D (2005 – ongoing)
- Commercialisation
CSIRO Fast Neutron and Gamma Radiography Technique

- Collect images (radiographs) using fast neutrons and high-energy gamma-rays
- Neutron attenuation: \( \frac{I_n}{I_{on}} = \exp(-\mu_{14} \rho x) \)
- Gamma attenuation: \( \frac{I_g}{I_{og}} = \exp(-\mu_g \rho x) \)
- Form ratio of mass attenuation coefficients:
  \[ R = \frac{\mu_{14}}{\mu_g} = \frac{\ln \left( \frac{I_n}{I_{on}} \right)}{\ln \left( \frac{I_g}{I_{og}} \right)} \]
- From the radiographic images and the calculated R values, form a 2D composite image showing average density and composition
Fast neutron and gamma-ray interrogation of air cargo containers

R-Values:
14 MeV Neutrons & $^{60}$Co Gamma Rays

R value

- Lead
- Iron
- Aluminium
- Glass
- Concrete
- Teflon
- Graphite
- TNT
- Cotton
- Paper
- Rice
- Heroin
- Morphine
- Water
- Ethanol
- Polythene
Comparison of Neutron and High Energy X-Ray Dual Beam Radiography for Air Cargo Inspection

- **Advantages of Dual High Energy X-Ray Systems**
  - Generally better penetration, depending on material
  - Single interlaced source (e.g. 5 and 9 MeV)

- **Advantages of Fast Neutron and Gamma/X-ray Systems**
  - Much better sensitivity to material composition
  - Can potentially discriminate various classes of organic material
Customs Scanner Facility at Brisbane International Airport

- Examination area
- ULD reload point
- CSIRO Air Cargo Scanner
- ULD unload point
- 16 m

CSIRO. Fast neutron and gamma-ray interrogation of air cargo containers
Brisbane Airport Scanner: Sources

High brightness + good penetration
- $>5 \times 10^9$ n/s commercial DT 14 MeV neutron generator (Thermo A-711)
- 135 GBq $^{60}\text{Co}$ $\gamma$-ray source

Small active volume
- $4 \times 4$ mm for gamma-ray source
- Neutron beam spot ~ 10 mm

Monochromatic
- Avoids beam-hardening problems
- Measurement of R is independent of material thickness
14 MeV Neutron Generator

**Require**
- High neutron output ($\sim 10^{10}$ n/s continuous)
- Small volume target ($\sim <25$mm)
- High availability (>95%)
- High reliability
- Lifetimes of neutron tube $\sim 2000$ hours (depends on output)
- Reasonable purchase and running costs

**Commercial systems** available from Thermo, Sodern and others
Detector systems

- **Requirements:**
  - ~4.3m long array
  - High efficiency for 14 MeV neutrons and ~1 MeV X- or gamma-rays
  - Good spatial resolution
  - Low cost per channel

- **Approach**
  - Scintillator + photodiode readout
  - Plastic scintillator for neutrons,
  - CsI(Tl) for gamma-rays
  - CSIRO developed low-noise preamplifiers, shaping amplifiers and digital counting and readout
Detector System in Brisbane Scanner

- **Neutron detectors**
  - Plastic scintillator neutron detectors
  - Neutron detectors 20x20x75mm
  - 704 neutron detectors in modules of 16

- **Gamma-ray detectors**
  - CsI(Tl) gamma-ray detectors
  - Gamma detectors 10x10x50mm
  - 352 gamma detectors in modules of 32

- **Features**
  - Similar channel-to-channel performance
  - Less than US$200 per channel
Main Steps for Image Processing System

- Data preconditioning, registration, and geometry distortion corrections
- Correct scattering, cross-talk, and background radiation
- Noise removal (smoothing) and increase definition (sharpening)
- Determine composite R value and map it to hue, and map gamma attenuation to lightness
- Background subtraction
Image Display System and GUI Design

- Short image analysis time ~ 2 mins
- Complex images
  - Wide range of cargo types – perishables to mining machines
  - Large variations of cargo size
  - Various packing methods
  - Overlaying material types
- Multi-users and security

  - Pre-optimised image menu to start
  - Intuitive and easy to use image manipulation tools
  - Simple and clear GUI, large icons/tools buttons
  - Multi-users login and user image libraries
Image Display System – Manipulating Tools

- Image manipulating tools
  - Brightness, contrast, zoom (mouse gesture controlled)
  - Full colour, black/white, organic/inorganic only
  - Histogram equalization, density contours
  - Material type indicator

- Highlight window
  - With independent image manipulation tools

- Background removal

- ULD info / User Library
Reference Scanner: ULD Loaded with Mixed Cargo

From left-to-right, the cargo contains assorted computer equipment, heavy steel industrial items, mixed boxes of food stuffs (including bottled drinks, frozen meat and fish, boxed apples) and boxes containing office files and papers.
CSIRO Air Cargo Scanner: Radiation Safety

- Dose rate at perimeter of exclusion zone < 0.5 \( \mu \text{Sv/hr} \)
- **Safety interlocks** to prevent access when sources are on or exposed
- **Dose delivered to cargo** \( \sim 12 \ \mu \text{Sv} \) (at a scan speed of 1m/min), similar to 2-hour plane flight at 10,000m
- The **residual induced radioactivity** \( \sim 1000 \) times lower than the natural radioactivity in a typical cargo.
- Delivered dose complies with legislation regarding **food and pharmaceutical irradiation** (<10 mGy for 14 MeV neutrons)
- ARPANSA approved
Trial Outcomes

- CSIRO Air Cargo Scanner trialled by Australian Customs on incoming air cargo at Brisbane International Airport: June 2006- March 2007

- Demonstration of FNGR for material discrimination and ability to make hidden organic materials more obvious.

- Consolidated cargo was scanned in less than two minutes once the cargo is at the scanner, thus allowing high volumes of cargo to be screened rapidly.

- Comparative tests against two commercial X-ray scanners in Brisbane on a range of cargo showed that, with improved spatial resolution (5 mm detectors or smaller) and multi-view capability, the CSIRO Air Cargo Scanner has the potential to significantly outperform the current best commercial X-ray air cargo scanners.
Reference Scanner at Lucas Heights

- Reference Scanner to provide a platform for trials (e.g. improvised explosive devices), enhancements, new applications, etc.
- Simulate Brisbane scanner but with:
  - Weaker sources (neutrons \(\sim 10^8\) n/s, 2.4 GBq Co60)
  - Reduced source-detector distance
  - Same detector sizes but reduced height of detector arrays (~1.9 m) and tunnel
  - Accommodate ULDs up to 1.7 m high and 2.5 m wide
  - Typical scan time ~few hours
High Resolution Reference Scanner

- **Reference Scanner upgraded in 2006/7** to assess and compare super-resolution and small detector methods for improving spatial resolution.

- Results have shown that the use of **small (5 mm) gamma detector elements provides better spatial resolution than super-resolution methods** using two offset columns of the 10 mm gamma detector elements used in the Brisbane Air Cargo Scanner.

- For the larger neutron detector elements, super-resolution provided an adequate improvement in resolution.

- The higher resolution images are a **significant aid in understanding complex, high-clutter cargos.**
Resolution Enhancements

5 mm pixels
Current Status

- Full-scale system developed and extensive trials conducted at Brisbane International Airport by Australian Customs – completed earlier this year
- Reference scanner built and operated in our laboratory
- Development of Mark-II system in conjunction with commercial partner expected to start imminently
  - Higher resolution X-ray imaging
  - Multi-view capability
  - Reduced footprint, easier deployment
  - Enhanced image processing and viewing software
- FNGR approach provides a powerful tool for locating a range of threat items, including narcotics, explosives and nuclear materials
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