PASSIVE NMIS MEASUREMENTS TO ESTIMATE SHAPE OF PLUTONIUM ASSEMBLIES
(Slide Presentation)

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OBJECTIVE

- PURPOSE: Estimate shape of plutonium assemblies using new signatures acquired by passive NMIS measurements (no external source)

- Applications
  - Identification of containerized regular shapes of plutonium
  - Identification by shape without template
  - Verification of shape for template initialization
  - Potential utility for estimating shape of holdup in plutonium processing facilities

- To illustrate the technique and test its feasibility, laboratory measurements have been performed with californium spontaneous fission sources as a surrogate for plutonium
TECHNIQUE HAS A NUMBER OF ADVANTAGES

- Passive – requires no external source for plutonium measurements
- Stationary – no scanning of the assembly is required
- Penetrative – shape is estimated from neutron emissions
- Obscurable – spatial resolution can be deliberately degraded by changing detector size and/or timing resolution
- Inexpensive – Majority of NMIS components are commercial products
- Portable – detection system is transported to the item, not vice versa.

TECHNIQUE ESTIMATES PU-240 SPATIAL DISTRIBUTION USING SUPERPOSITION

- Principle: estimate shape of distributed source by superposition of point sources

![Diagram of different shapes: point, line, ring, cylindrical surface, annulus, solid, spherical surface, shell, solid]
PASSIVE NMIS MEASUREMENTS OF PLUTONIUM

- Up to five detectors – each sensitive to both neutrons and gammas
- Neutron and gamma counts arise from
  - Spontaneous fission of Pu-240
  - Fission of Pu-239 induced by Pu-240 neutrons
- Detector pulses mark time of neutron/gamma count
- Counts in one detector correlated with counts in another detector

DETECTORS

FISSILE (Pu-239) ASSEMBLY WITH INHERENT SOURCE (Pu-240)

INSTRUMENTATION AND CONTROLS

NMIS CORRELATION SIGNATURES

- Average rate of pairs of coincident detector counts
- Distributed over time–delay between individual detectors in pair

One Pair: Distribution Accumulated Over $10^6$ – $10^9$ Pairs

- Three kinds of pairs
  - Gamma–gamma pairs (G–G): short time–delays
  - Gamma–neutron pairs (G–N): intermediate time–delays
  - Neutron–neutron pairs (N–N): long time–delays
**NMIS EXPERIENCE WITH PLUTONIUM**

- NMIS has been perceived as a strictly active method.
- Recent experience has demonstrated that NMIS is capable of performing passive identification of plutonium components.
- NMIS scored 5 for 5 in DSWA-sponsored blind tests with pits at LANL:
  - Detected all false declarations.
  - Determined true identity of falsely declared items – including $(\alpha,n)$ source substituted for one pit.
- More recent measurements at PANTEX were equally successful at identifying pits.
- Subsequent analyses have demonstrated that passive measurements can estimate mass using a californium–252 source as the only calibration standard.

**INSTRUMENTATION AND CONTROLS**
PASSIVE NMIS MEASUREMENTS SCALE DIRECTLY WITH SPONTANEOUS FISSION RATE

- Passive NMIS measurements of four Cf-252 spontaneous fission sources of nearly identical mass

Passive Coincidence Distribution

Area Under Distribution vs Cf-252 mass

HIGHER ORDER CORRELATIONS

- Previous correlation signatures are second-order
  - Measure distribution of two-way coincidence
  - (count rate is first-order in this context)
- Method recently generalized to measure higher order correlations
  - N-th order correlation: distribution of N-way coincidence
- Third- and fourth-order correlation analyses have been implemented in NMIS
- Third-order correlation analysis has been applied to measurements of uranium
- First implementation and application of higher order correlations in nuclear measurements – NMIS 1997
HIGHER ORDER CORRELATIONS ARE MORE SENSITIVE TO FISSION MASS

- Single neutrons
- Correlated pairs
- Bicorrelated triplets

THIRD-ORDER CORRELATION SIGNATURES

- Average rate of triplets of coincident counts (bicoincidence)
- Distributed over time-delays between
  - First and second detection
  - First and third detection

One Triplet: Distribution Accumulated Over $10^6 - 10^9$ Triplets
THIRD-ORDER CORRELATION SIGNATURES

- Four kinds of triplets
  - Gamma–gamma–gamma triplets (G–G–G)
    - Three gammas counted in rapid succession
    - Short time–delays between counts
  - Gamma–gamma–neutron triplets (G–G–N)
    - Two gammas counted in rapid succession, neutron counted later
    - Short time–delay between two gammas, longer time–delay to neutron
  - Gamma–neutron–neutron triplets (G–N–N)
    - Gamma counted first, two neutrons counted later
    - Long time–delays between gamma and each neutron
  - Neutron–neutron–neutron triplets (N–N–N)
    - Long time–delays between each neutron count
PASSIVE MEASUREMENT OF SPONTANEOUS FISSION SOURCE

INSTRUMENTATION AND CONTROLS
PASSIVE MEASUREMENT OF SPONTANEOUS FISSION SOURCE

LOG₁₀ BICOINCIDENCE RATE

G-G-G PEAK
G-G-N RIDGE 1    G-G-N RIDGE 2

INSTRUMENTATION AND CONTROLS
THIRD-ORDER CORRELATION MEASURES FLIGHT DISTANCE FROM SOURCE TO EACH DETECTOR

LOG, BICOINCIDENCE RATE

INSTRUMENTATION AND CONTROLS
THIRD-ORDER CORRELATIONS PASSIVELY MEASURE NEUTRON FLIGHT DISTANCE

LOG$_{10}$ BICOINCIDENCE RATE

G-G-G PEAK
G-G-N RIDGE 1  G-G-N RIDGE 2

TIME-DELAY [1-2] (nsec)

INSTRUMENTATION AND CONTROLS
THIRD-ORDER CORRELATION MEASURES FLIGHT DISTANCE FROM SOURCE TO EACH DETECTOR

INSTRUMENTATION AND CONTROLS
THIRD-ORDER CORRELATIONS PASSIVELY MEASURE NEUTRON FLIGHT DISTANCE

LOG₁₀ BICOINCIDENCE RATE

G-G-G PEAK
G-G-N RIDGE 1  G-G-N RIDGE 2

TIME-DELAY [1-2] (nsec)

INSTRUMENTATION AND CONTROLS
Neutrons emerge from source according to its fission spectrum.

Fission neutrons incident on the detector are counted according to its efficiency.

Probability of counting fission neutron: fission spectrum x detection efficiency.

Detection probability is a function of neutron speed:
\[ E = \frac{1}{2} m v^2 \]
MEASURING NEUTRON FLIGHT DISTANCE

- Neutron flight time from source to detector is distance / speed
- Time-of-flight spectrum is dilated by flight distance
- Time-of-flight spectrum provides a measure of distance to the source
CONCEPT FOR POINT SOURCE LOCATION

- Analogous to GPS
  - Source: point fission source
  - Receivers: uncollimated radiation detectors
- Detectors measure distance from source
- General case: four detectors required to determine source location in 3D-coordinates
- Source lies at single point common to three circles
- Requires three measurements of relative distance - (R_1, R_2, R_3)

PASSIVE MEASUREMENTS OF SPONTANEOUS FISSION POINT SOURCE

- Small Cf-252 spontaneous fission source
- Measured at seven positions by three 100 x 100 x 100 mm³ detectors
Three G–G–N ridges extracted from each of seven measurements

Time–of–flight spectrum converted to speed distribution

Empirical fit to average yielded distance–independent calibration

Neutron flight distances estimated from each measurement using single calibration

Empirical flight speed model estimates flight distance within (−27, +13) mm of actual (± 11%)

Good estimation for simple model – treats detectors as points

Extrapolation to short flight times used to eliminate contamination by gamma triplets

More sophisticated models will fit G–G–G peak and G–G–N ridge simultaneously to improve extrapolation
POINT SOURCE POSITION ESTIMATES

- Distance from each detector used to estimate source location
- Simple model estimates correct position to within 33 mm

GENERALIZATION FROM POINT SOURCES TO DISTRIBUTED SOURCES

- Distributed source: superposition of point sources
PASSIVE MEASUREMENTS OF SPONTANEOUS FISSION RING SOURCES (APPROXIMATE)

- Six small Cf–252 fission sources at $60^\circ$ intervals on three circles
  - Point (~ 10 mm), 160 mm, and 320 mm diameters (1/3 and 2/3 diameter of AT–400 container)
MEASUREMENT OF RING SOURCE DIAMETER

INSTRUMENTATION AND CONTROLS
MEASUREMENT OF RING SOURCE DIAMETER

RING SIZE

INSTRUMENTATION AND CONTROLS
MEASUREMENT OF RING SOURCE DIAMETER

LOG₁₀ BICOINCIDENCE RATE

RING SIZE

INSTRUMENTATION AND CONTROLS
PASSIVE MEASUREMENTS OF RING SOURCES

- Point source distinguishable from ring sources
- Estimated diameters of 160 mm and 320 mm rings deviate from actual by < 10 mm
CONCLUSIONS

- Passive NMIS measurements can infer the mass of plutonium assemblies
  - NMIS correlations scale directly with spontaneous fission rate (Pu–240)
  - NMIS correlations scale with fissile mass (Pu–239) and multiplication

- New third–order correlations can estimate the shape of fission sources (Pu–240 & Pu–239) from passive measurements

- Surrogate measurements of californium spontaneous fission sources have demonstrated the feasibility of this concept

- Measurements of various shapes of plutonium are necessary to continue the development of this technique
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