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

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OAK RIDGE NATIONAL LABORATORY

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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

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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**

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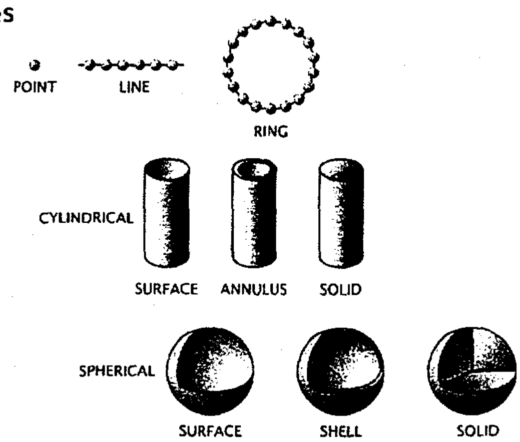
TECHNIQUE ESTIMATES PU-240 SPATIAL DISTRIBUTION USING SUPERPOSITION

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



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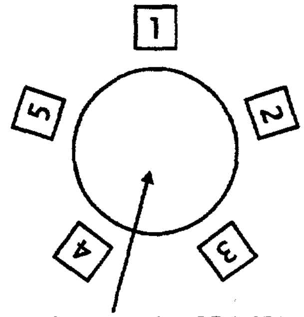
PASSIVE NMIS MEASUREMENTS OF PLUTONIUM

- 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)

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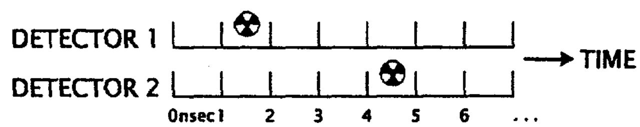
NMIS CORRELATION SIGNATURES

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



DELAY [1-2] = 3 nsec

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

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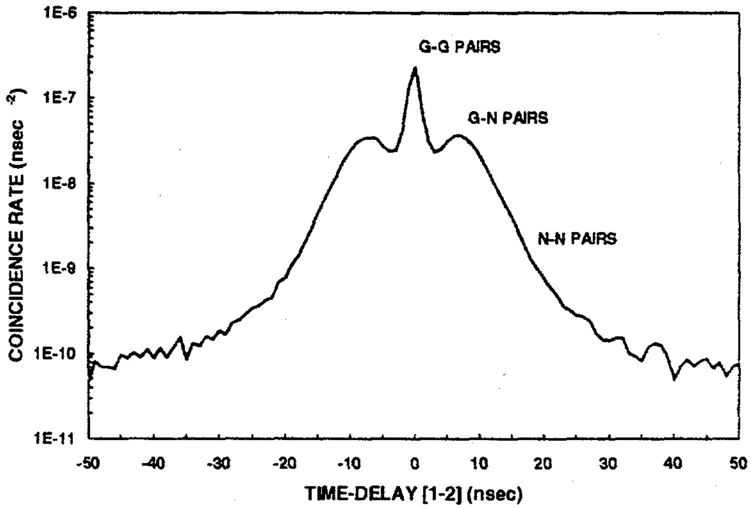
PASSIVE NMIS MEASUREMENT OF SPONTANEOUS FISSION SOURCE



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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 (α,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

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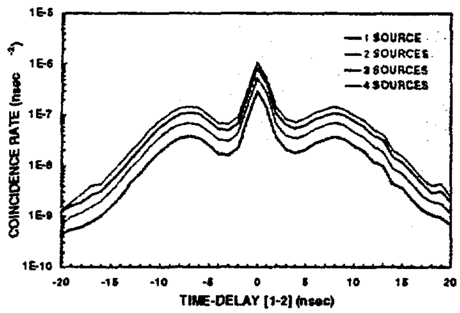
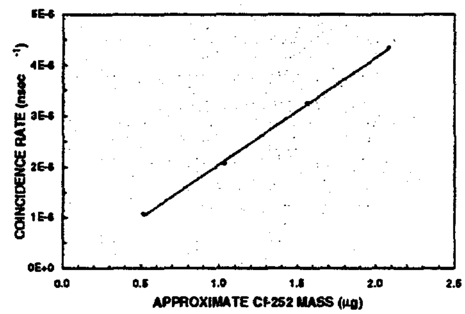
PASSIVE NMIS MEASUREMENTS SCALE DIRECTLY WITH SPONTANEOUS FISSION RATE

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

Passive Coincidence Distribution



Area Under Distribution vs Cf-252 mass



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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

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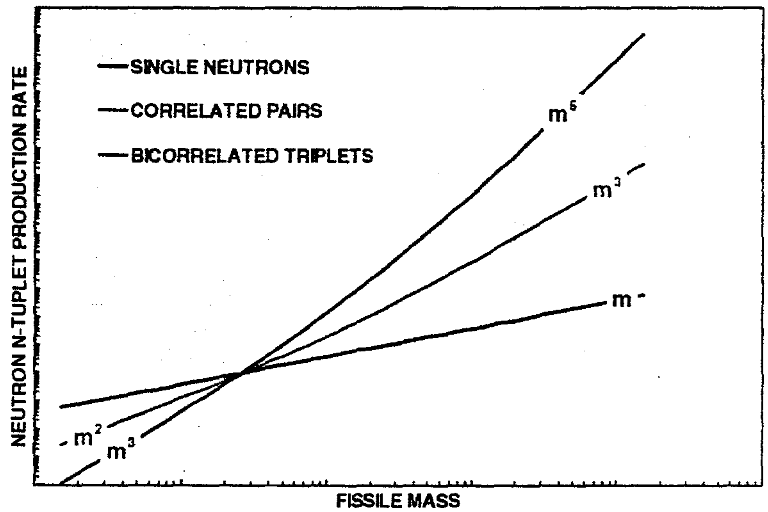
HIGHER ORDER CORRELATIONS ARE MORE SENSITIVE TO FISSILE MASS



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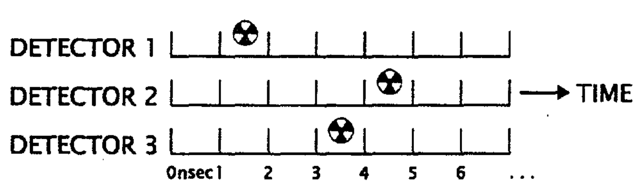
THIRD-ORDER CORRELATION SIGNATURES

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



DELAY [1-2] = 3 nsec
DELAY [1-3] = 2 nsec

One Triplet: Distribution Accumulated Over 10^6 - 10^9 Triplets

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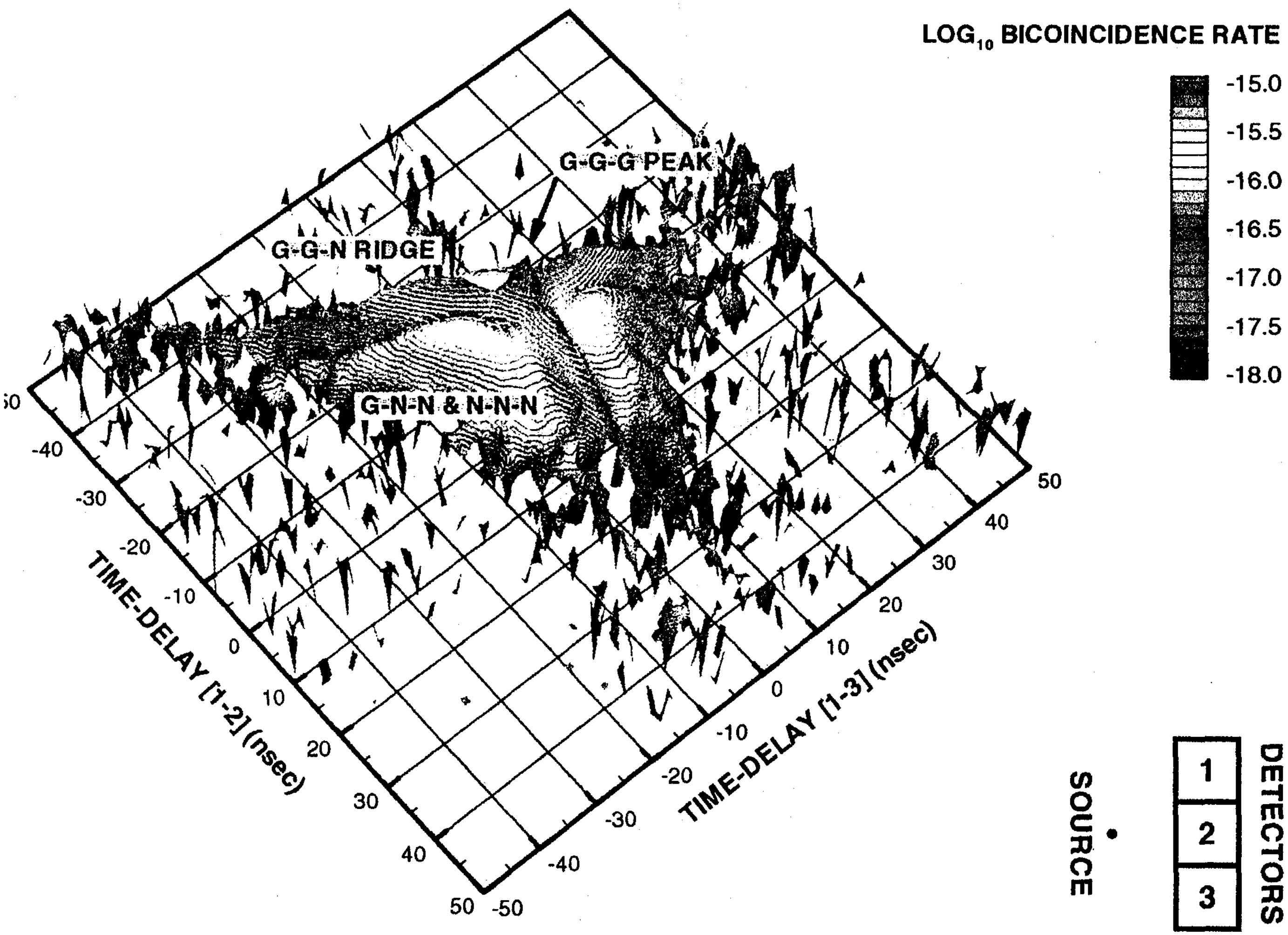
THIRD-ORDER CORRELATION SIGNATURES

- 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



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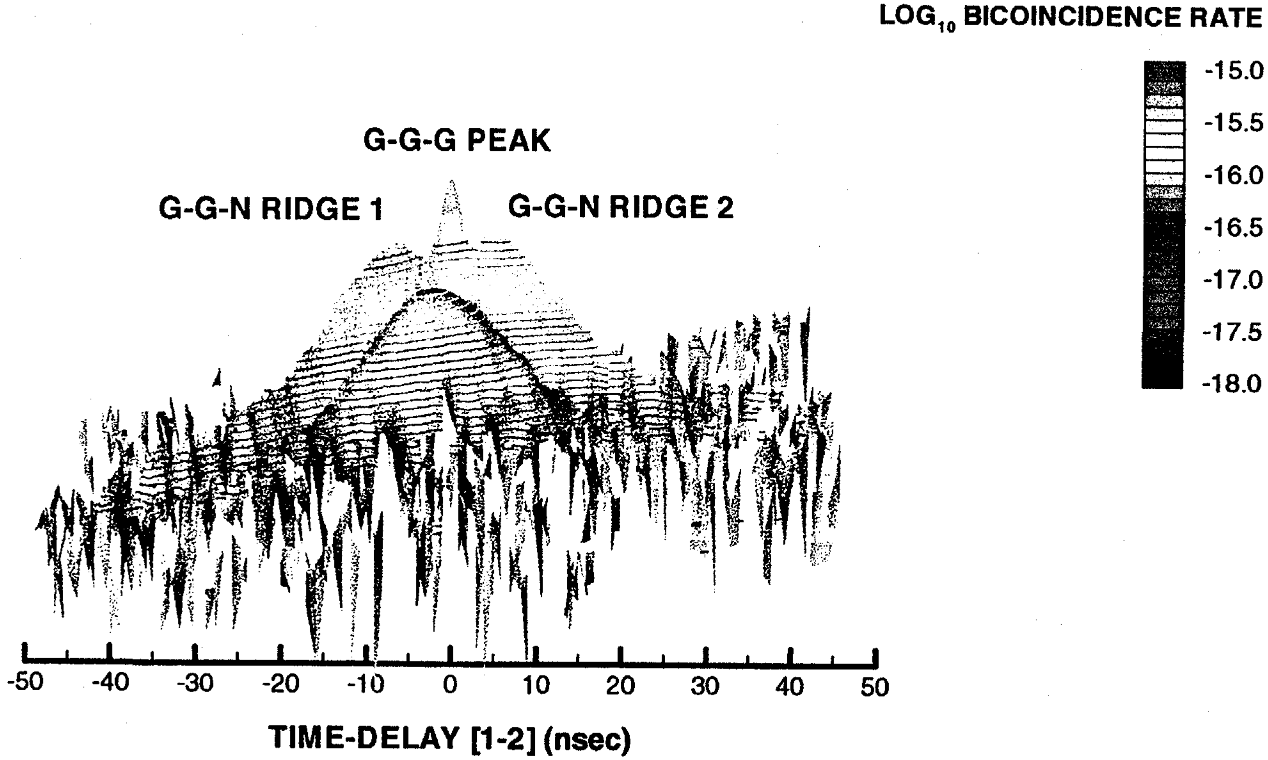
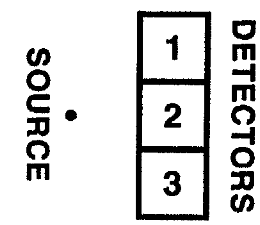
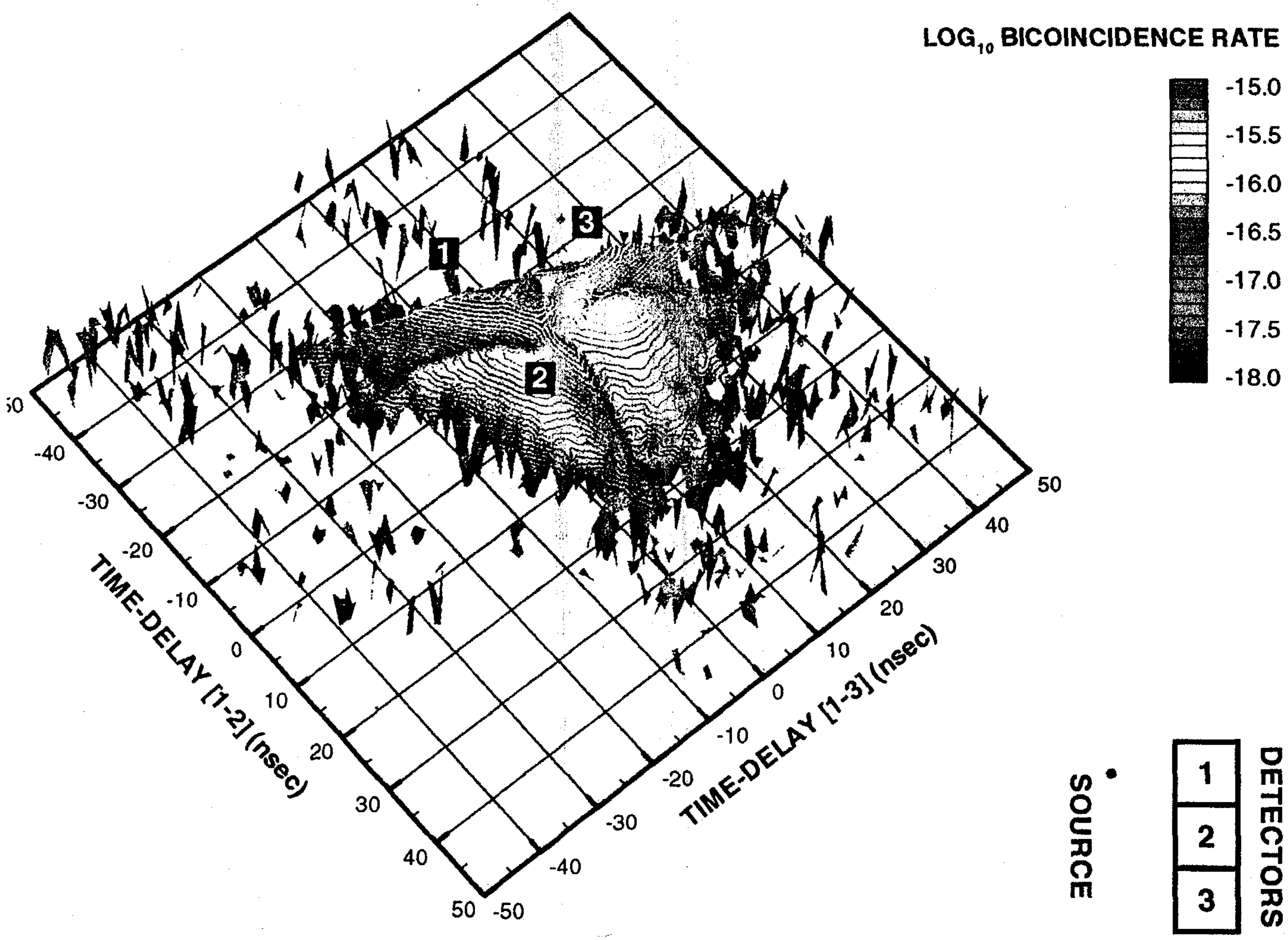
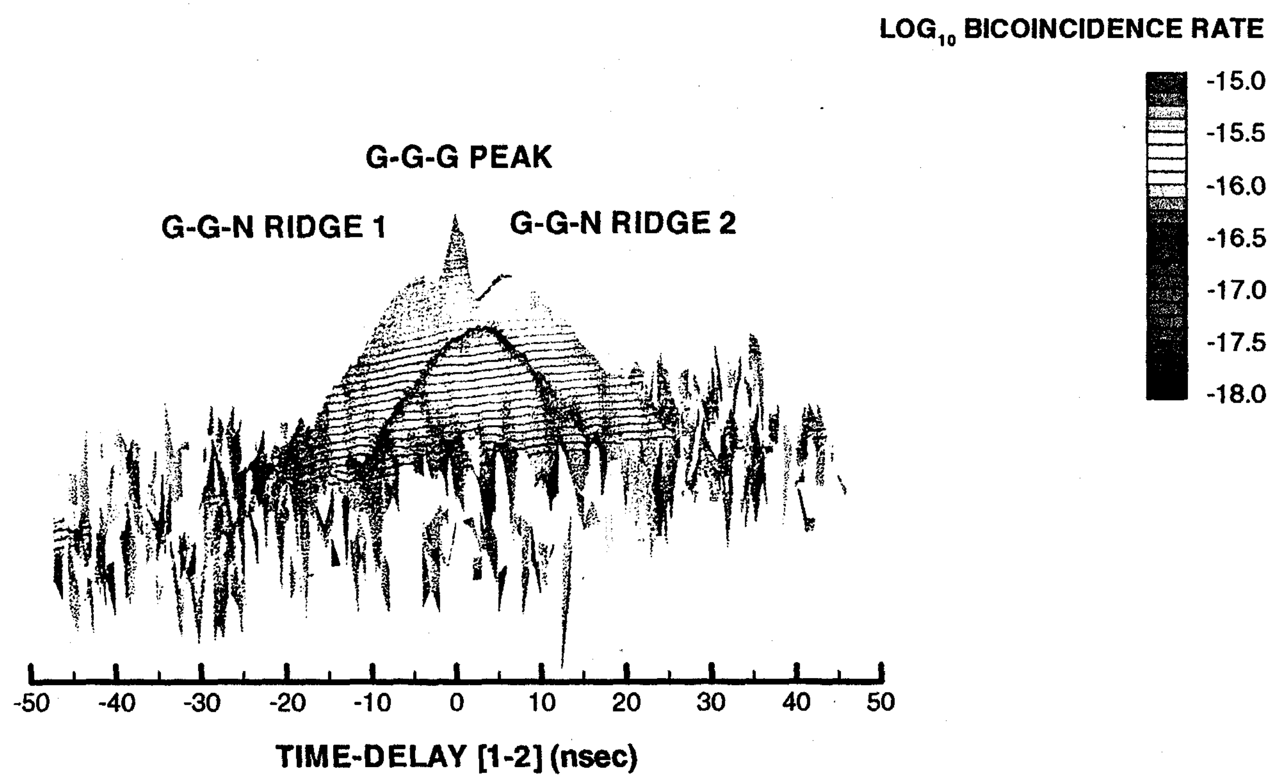


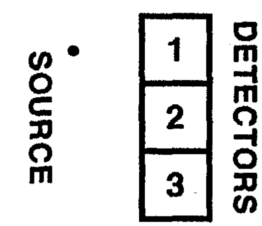


THIRD–ORDER CORRELATION MEASURES FLIGHT DISTANCE FROM SOURCE TO EACH DETECTOR



THIRD-ORDER CORRELATIONS PASSIVELY MEASURE NEUTRON FLIGHT DISTANCE





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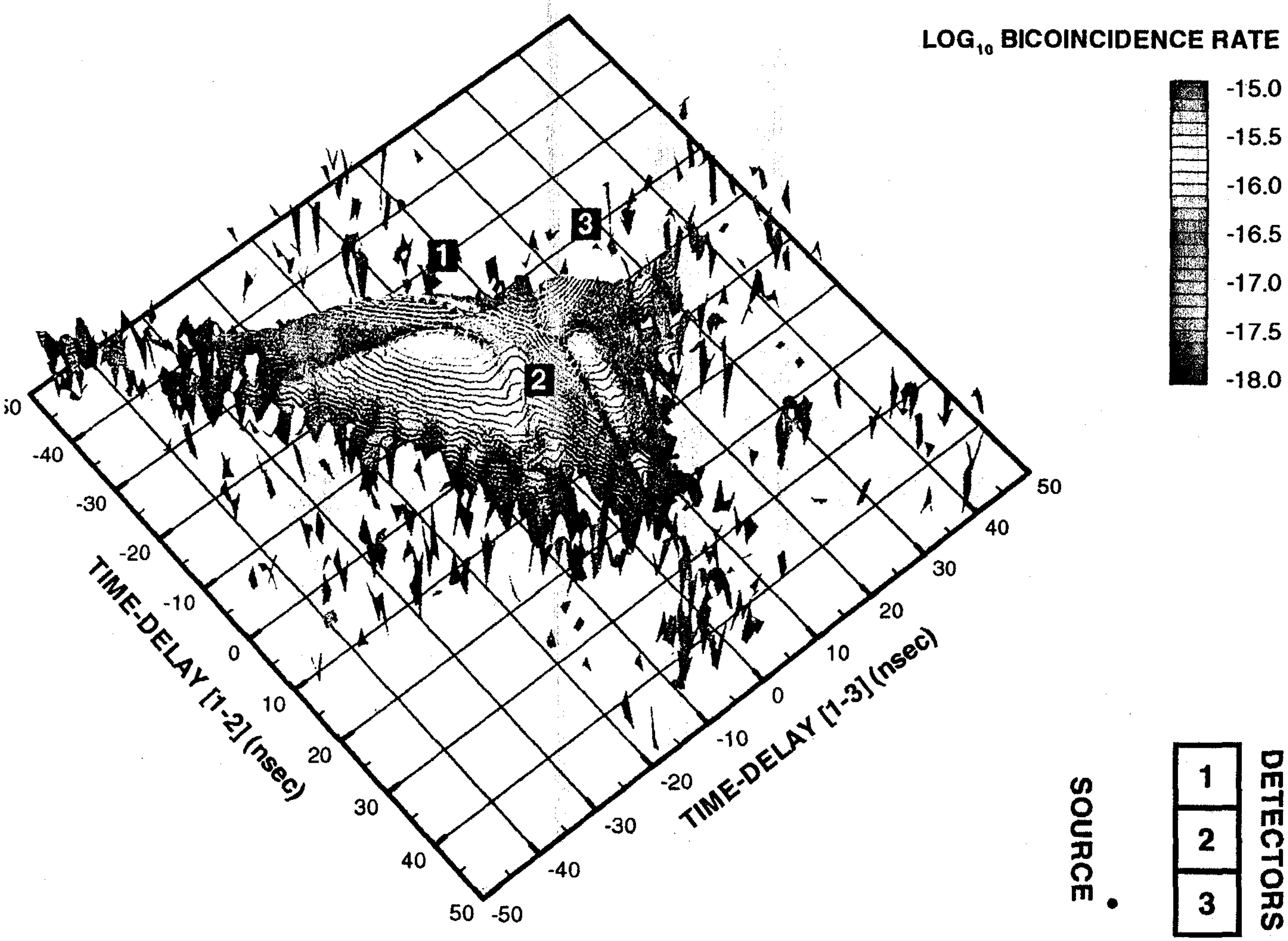

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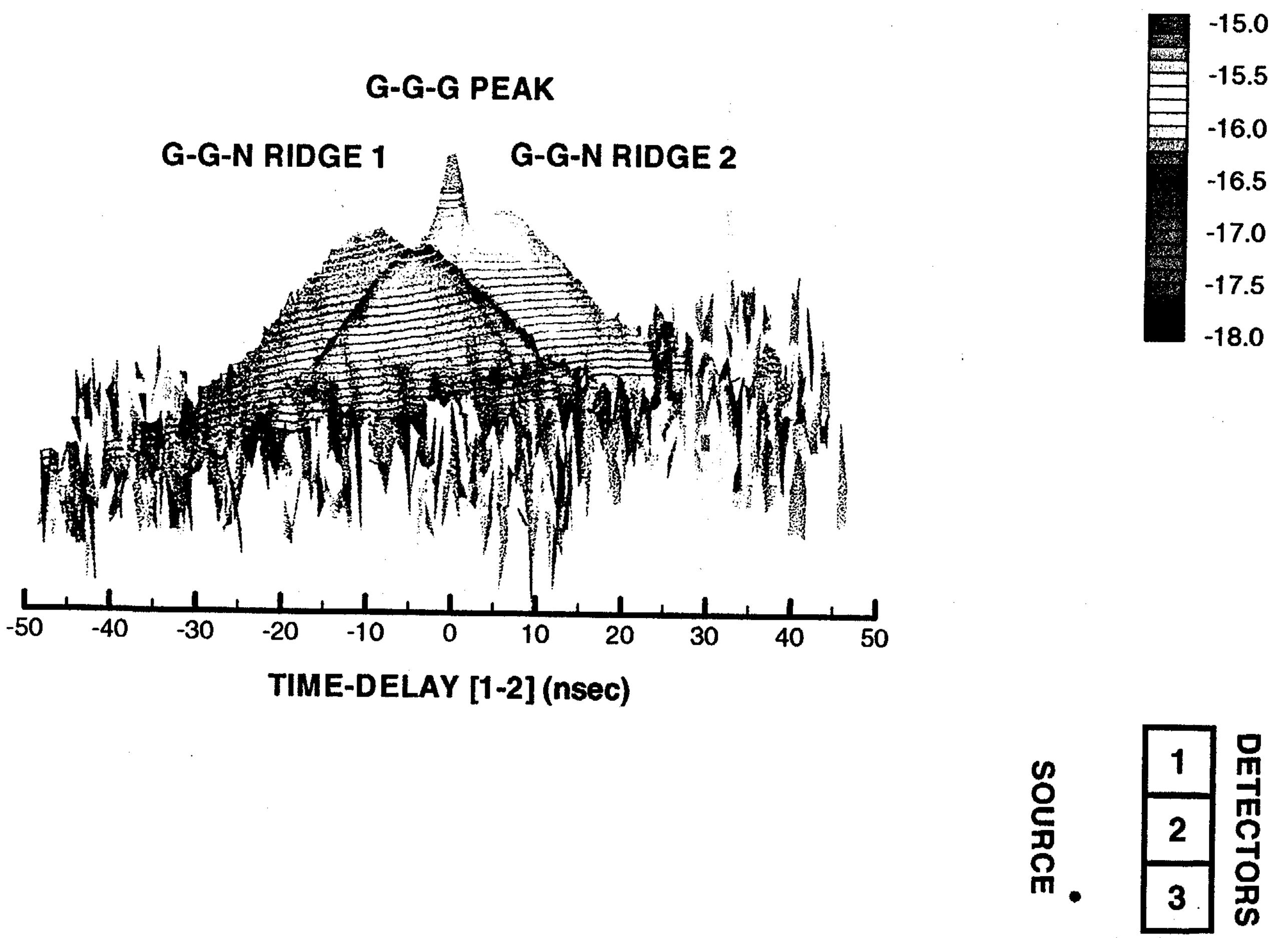

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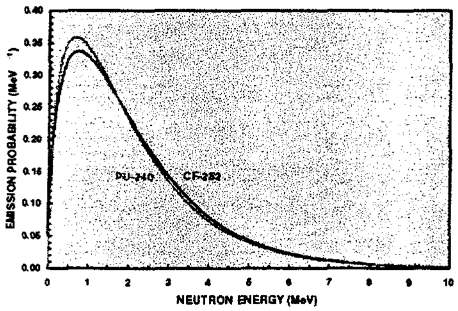
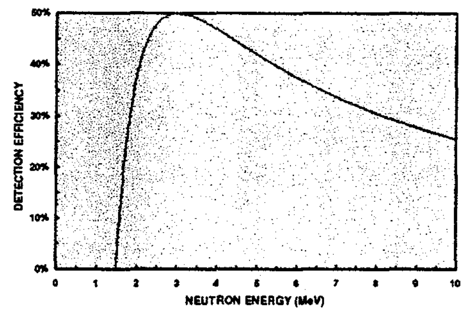
NEUTRON TIME-OF-FLIGHT SPECTRUM



Neutrons emerge from source according to its fission spectrum

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



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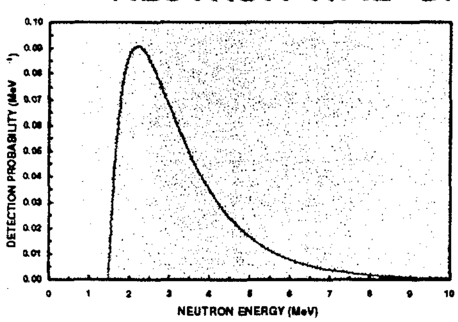
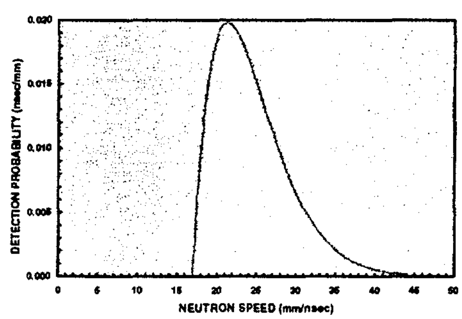
NEUTRON TIME-OF-FLIGHT SPECTRUM



Probability of counting fission neutron: fission spectrum x detection efficiency

Detection probability is a function of neutron speed:

$$E = {}^{1}/_{2}\, m\, v^2$$



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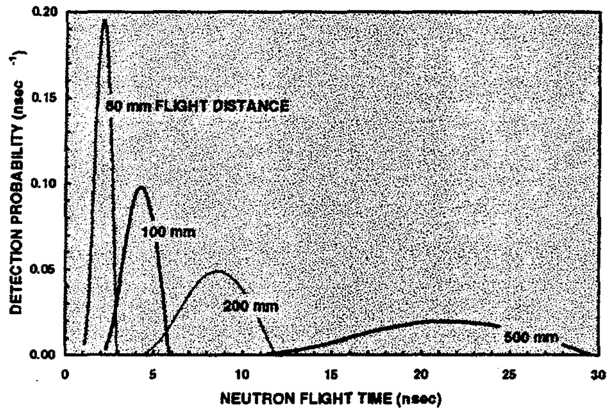
MEASURING NEUTRON FLIGHT DISTANCE



- 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

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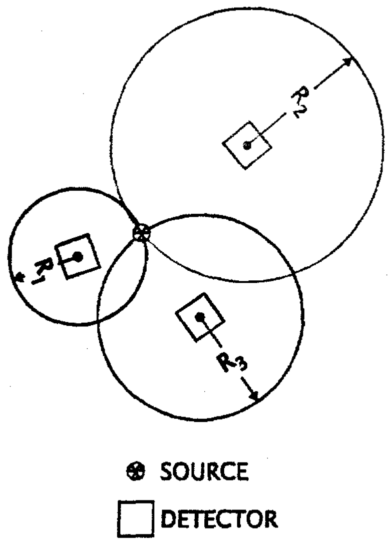
CONCEPT FOR POINT SOURCE LOCATION

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



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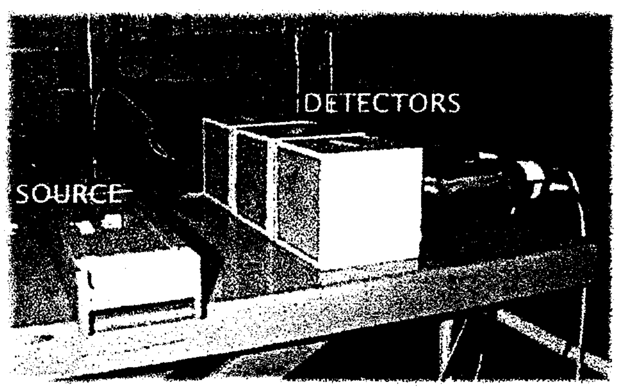
PASSIVE MEASUREMENTS OF SPONTANEOUS FISSION POINT SOURCE



- Small Cf-252 spontaneous fission source
- Measured at seven positions by three 100 x 100 x 100 mm^3 detectors

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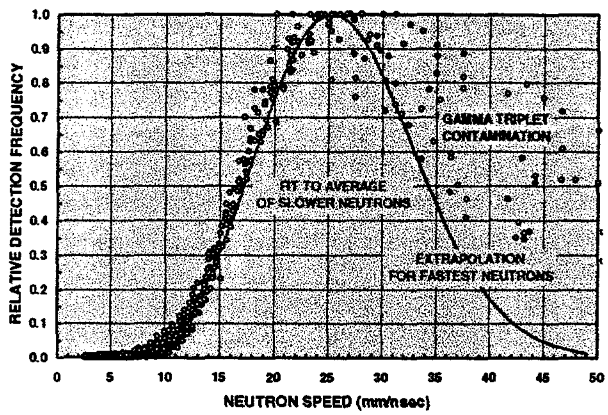
NEUTRON FLIGHT SPEED DISTRIBUTION



- 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

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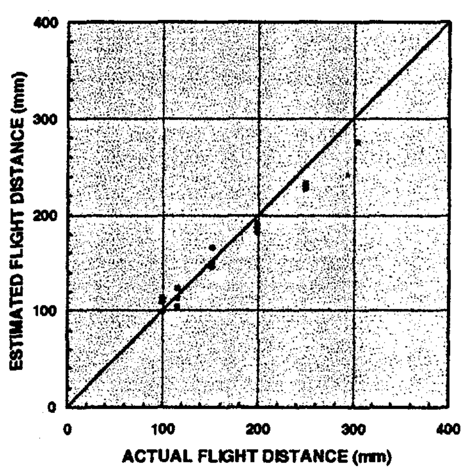
NEUTRON FLIGHT DISTANCE ESTIMATES

- 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



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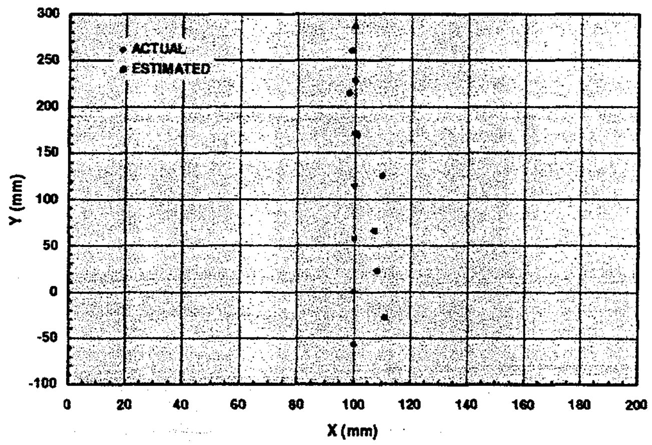
POINT SOURCE POSITION ESTIMATES



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

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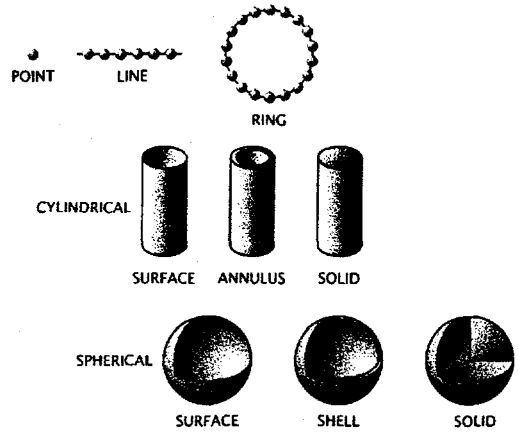
GENERALIZATION FROM POINT SOURCES TO DISTRIBUTED SOURCES

- Distributed source: superposition of point sources



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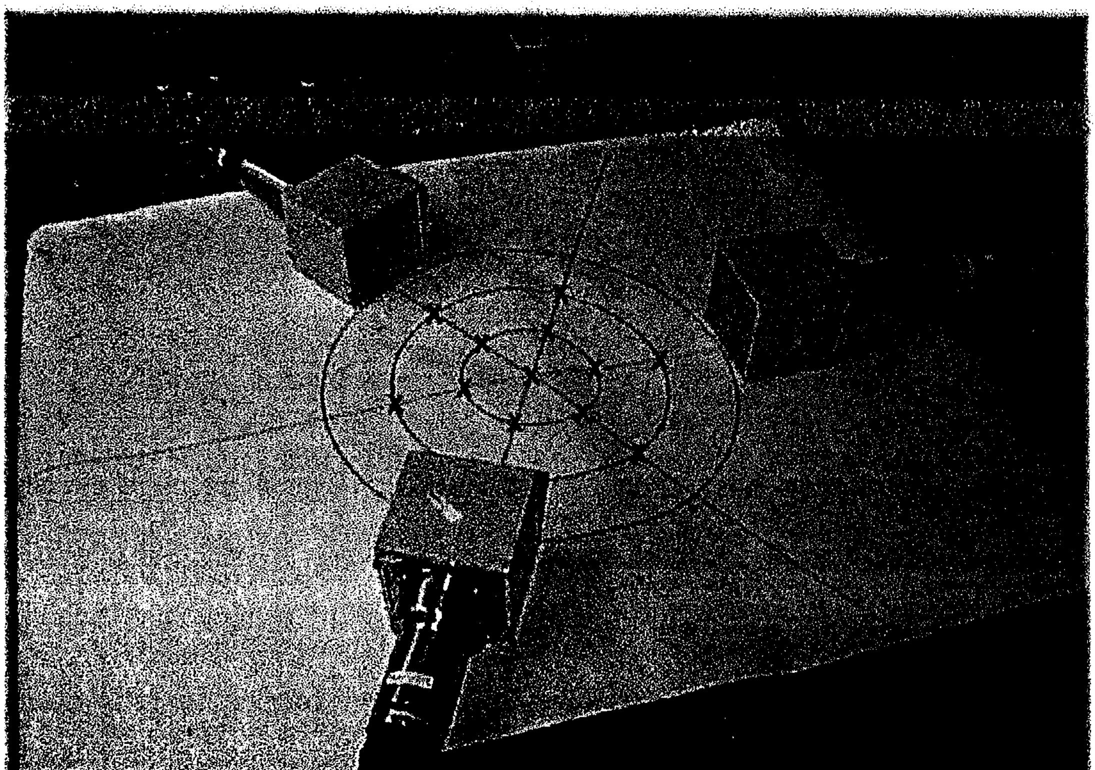
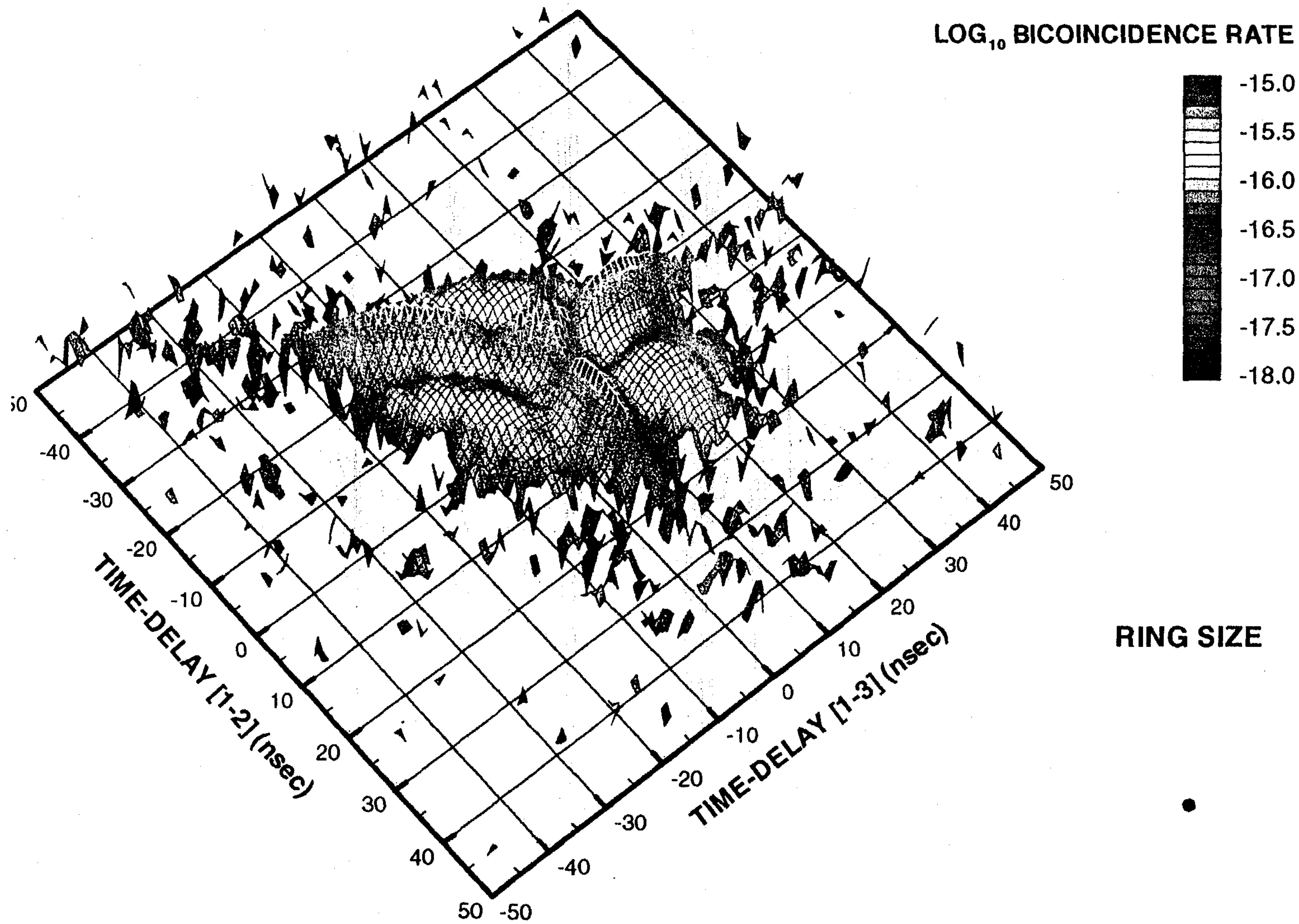
PASSIVE MEASUREMENTS OF SPONTANEOUS FISSION RING SOURCES (APPROXIMATE)



- Six small Cf–252 fission sources at 60^0 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



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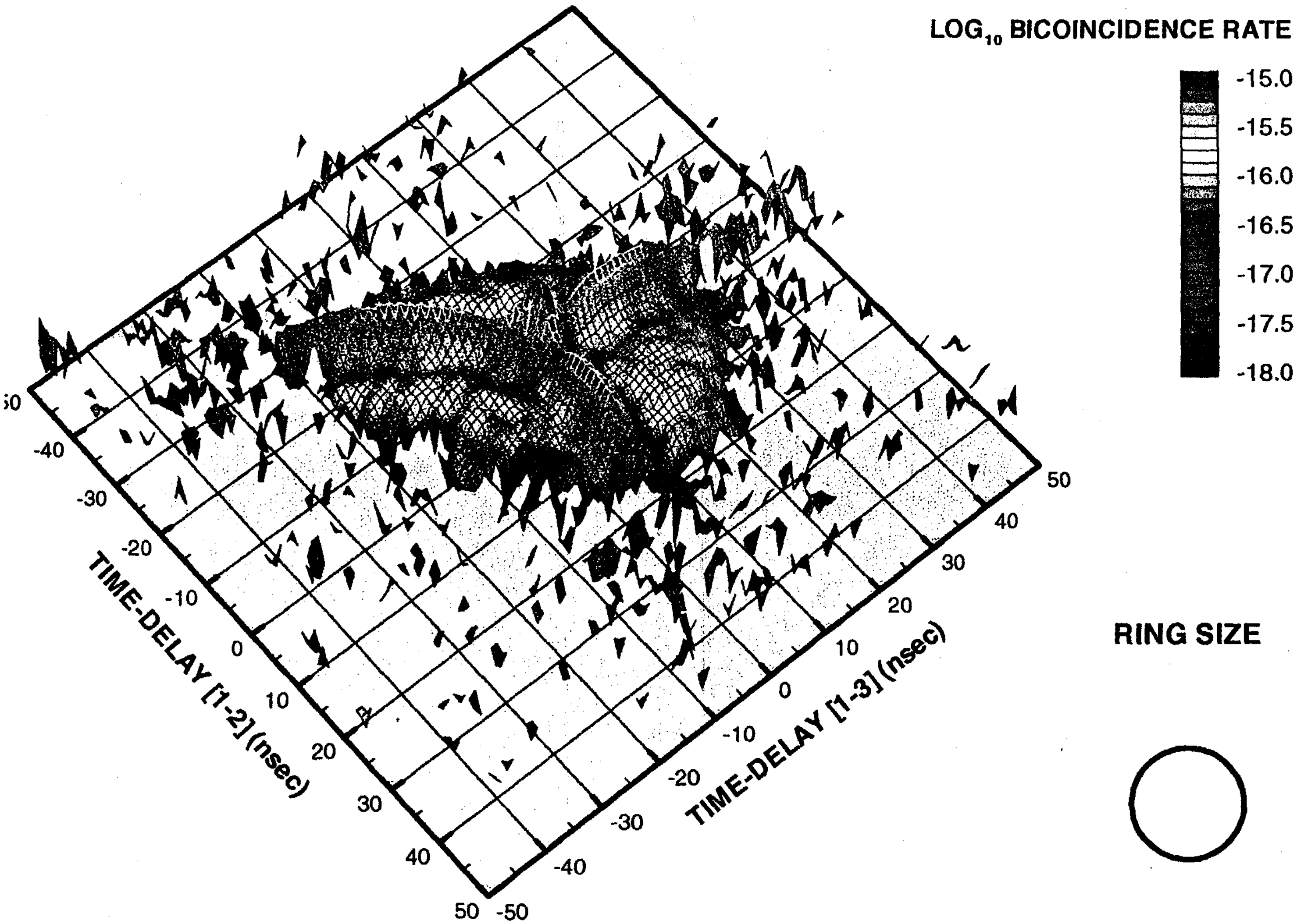

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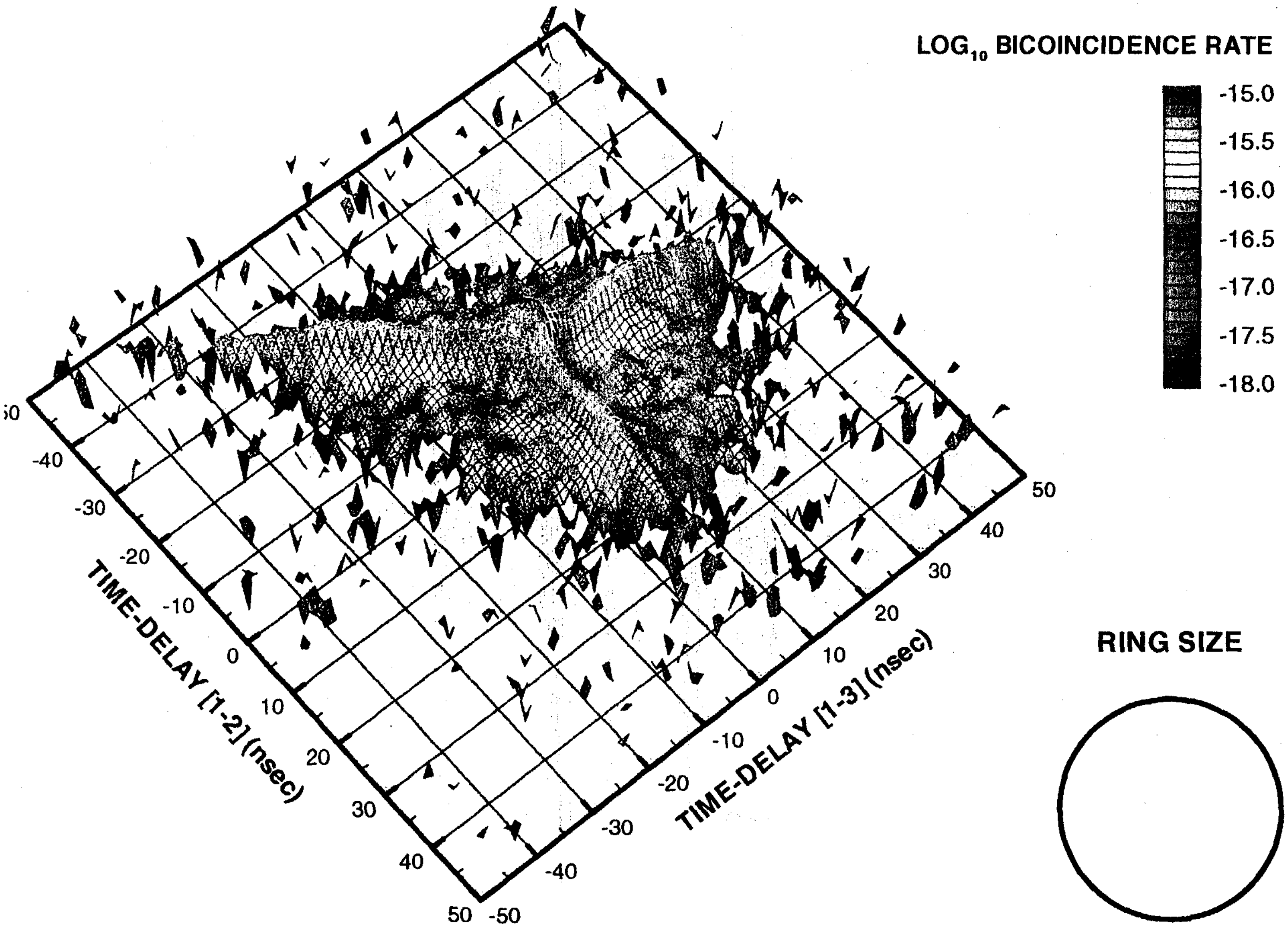
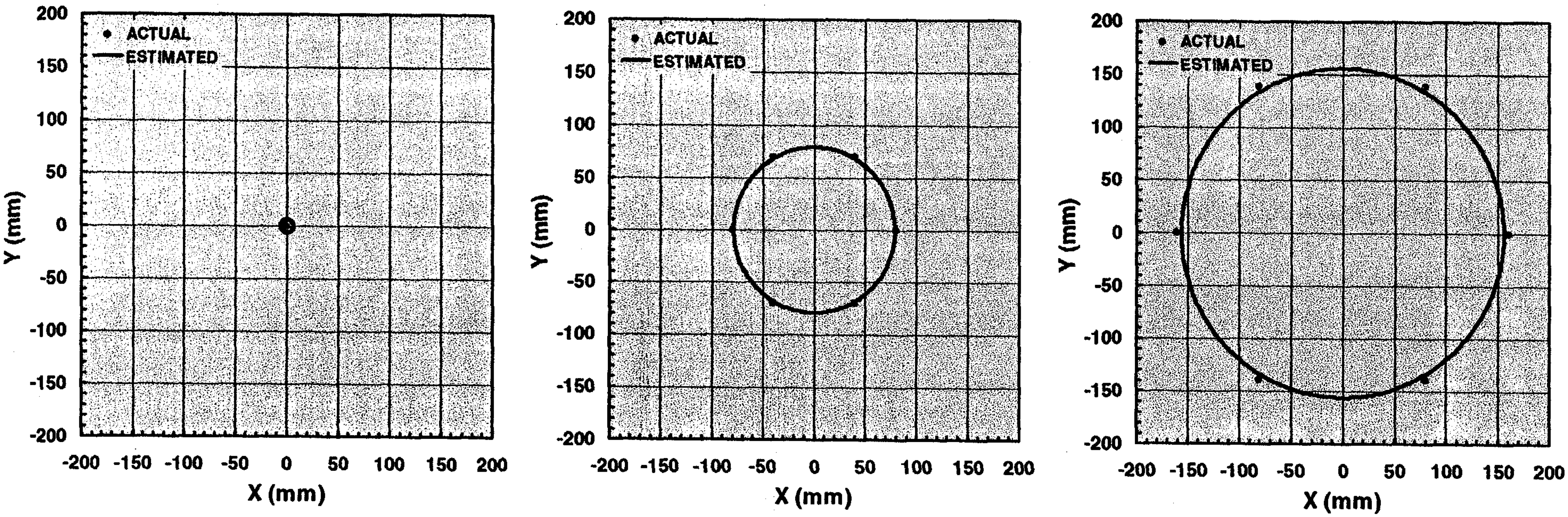


PASSIVE MEASUREMENTS OF RING SOURCES



- 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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