A Broad Coverage Neutron Source For Security Inspections

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ABSTRACT

- To meet the increasing demanding requirements for security safety inspections, a line-type neutron source employing a cylindrical IEC (C-IEC) is proposed for non-destructive "in situ" security inspections.
- Advantages include a line geometry, modularity, swithcability, variable source strength, low cost with minimum maintenance.
- Detailed description of a 1/3 scale cylindrical device is presented, intended to demonstrate that an elongated C-IEC produces a stable discharge with reasonably uniform neutron production along the cylindrical axis.
- A neutron production efficiency at the order of 10^6 n/J is desired – thus, several methods to maximize neutron production efficiency are discussed.
- Results of a 2-D computer code(MCP) using a Monte Carlo numerical approach for the C-IEC device are presented together with an analysis of neutron yield vs. operation parameters.

Outline

- Intro. of Neutron Activation Analysis
- IEC device description
- Mathematical model and numerical calculation of neutron yields
- Tunable x-ray source concept
- Schematic design of the security inspection system
- Conclusion and discussion

Introduction of NAA

- TNA (Thermal neutron analysis)

  (n, γ): Hydrogen, Chlorine (common in drugs), Nitrogen etc.

- FNA (Fast neutron analysis)

  $(n, n'\gamma)$: Oxygen, Carbon, Nitrogen, Chlorine, Hydrogen, Phosphor, Sulfur etc.

- PFNA (Pulsed FNA) with time-of-flight technique

  Reduce background “noise”

Three Techniques Commonly Used in Explosive Detection Systems – Methods Compliment Each Other, and IEC Offers Chance to Combine Methods

	TNA	FNA	X-ray
ELEMENT IDENTIFICATION			Element density
Nitrogen	Low	High	-
Carbon	Very Low	Very High	-
Oxygen	NA	High	-
Hydrogen	High	High	-
Chlorine	Very High	High	-
Phosphor	NA	High	-
Sulfur	NA	High	-
C/O Ratio	Low		-
Background Noise	High	Low	NA
Imaging	Limited	Depth information	High resolution
Source design	Thermalization media	Direct	Direct
Typical Application	Small suitcase	Suitcase to cargo	to cargo; NG for plastics.
Maintenance Cost	High	High	Low

IEC Device Description

- History & development.
  - Spherical IEC (SIEC) first proposed by Farnsworth in 1950's.
  - Studied theoretically and experimentally:
    - R.L. Hirsch in 1969.
    - Cylindrical IEC studied by T.J. Dolan (UI) in 1970.
    - Star-mode C-Device IEC developed by Fusion Group at UI in 1990's.
    - Los Alamos National Lab, University of Wisconsin, Kyoto University, Tokyo Inst. of Technology, and Kansai University studies.
- Description of Spherical IEC (SIEC)

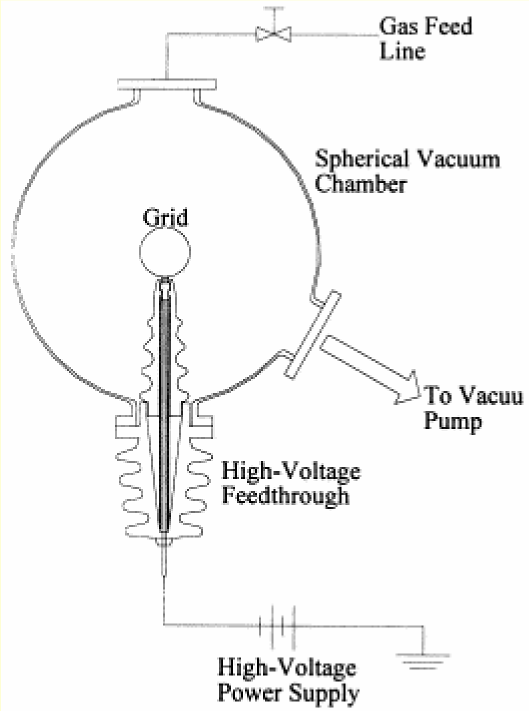


Fig. 1 Spherical IEC Device

Cylindrical IEC. The C-IEC geometry is best suited for inspection system.

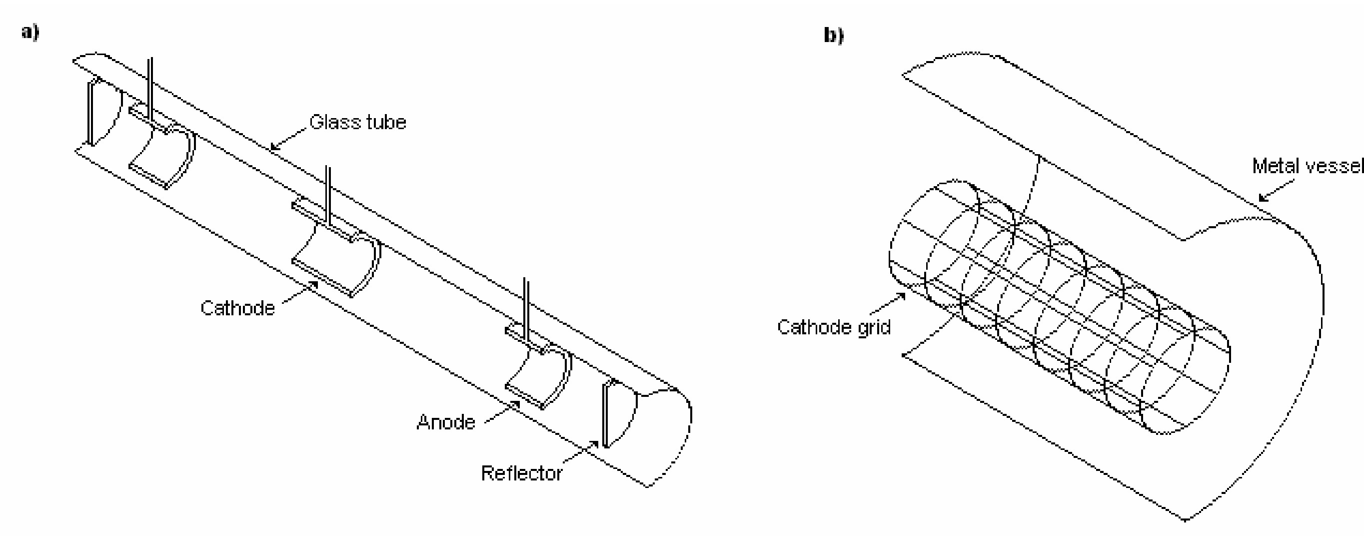


Fig. 2 Cylindrical IEC Device

Security System Goals

- Present SIEC demonstrates D-D neutron yields up to 10^7 n/s (steady state), or 10^9 n/s (pulsed).
- Goals for station – D-D yields of 10^8 n/s and D-T of 10^{10} n/s at steady state.
- Steady-state or ms pulse with C-IEC.
- High yield data for C-IEC lacking – need to rely on computational extrapolation.

Experimental Studies and Results from EIXL Vlasov-Poisson Solver Indicate Deep Double Well Possible, Hence Improved Efficiency

- Results from previous work at UI (using EIXL code) for an SIEC device.
  - Double potential wells observed.
  - Certain ratio of I_e/I_i and large angular momentum required.

EIXL Calculational Results Show Double Well and Strong Ion Density Peaks, as Desired

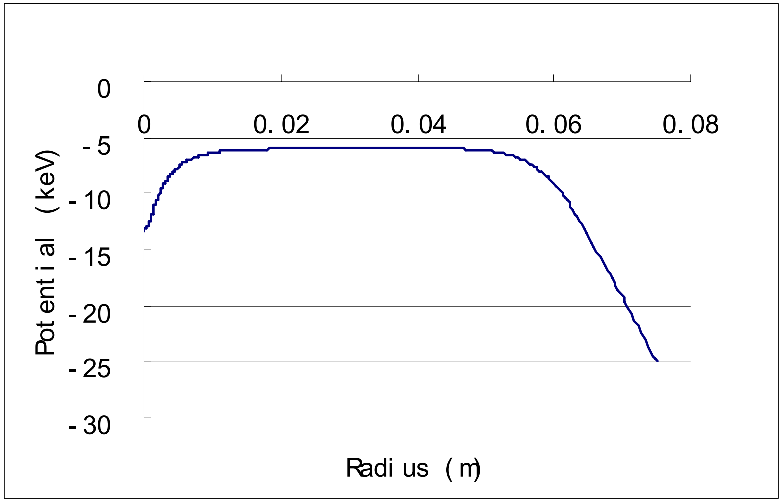


Fig. 3a. Potential distribution along the radius

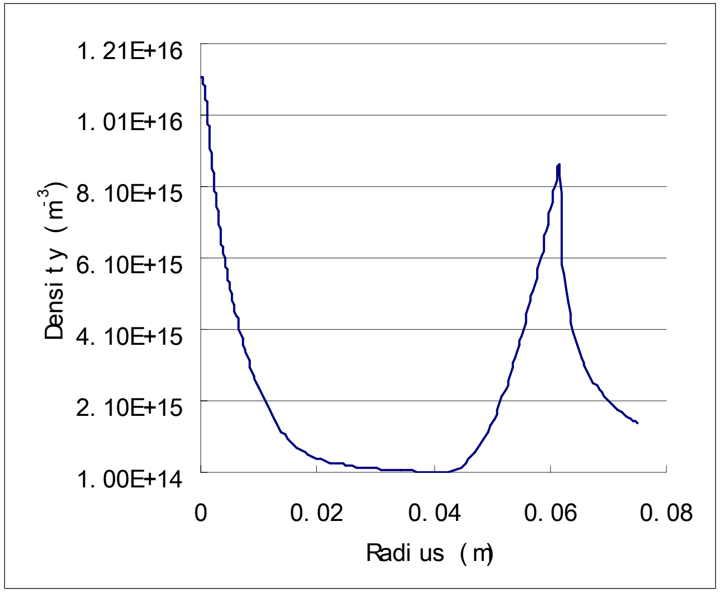


Fig. 3b. Ion density distribution along the radius

Parameters for EIXL Calculation for SIEC

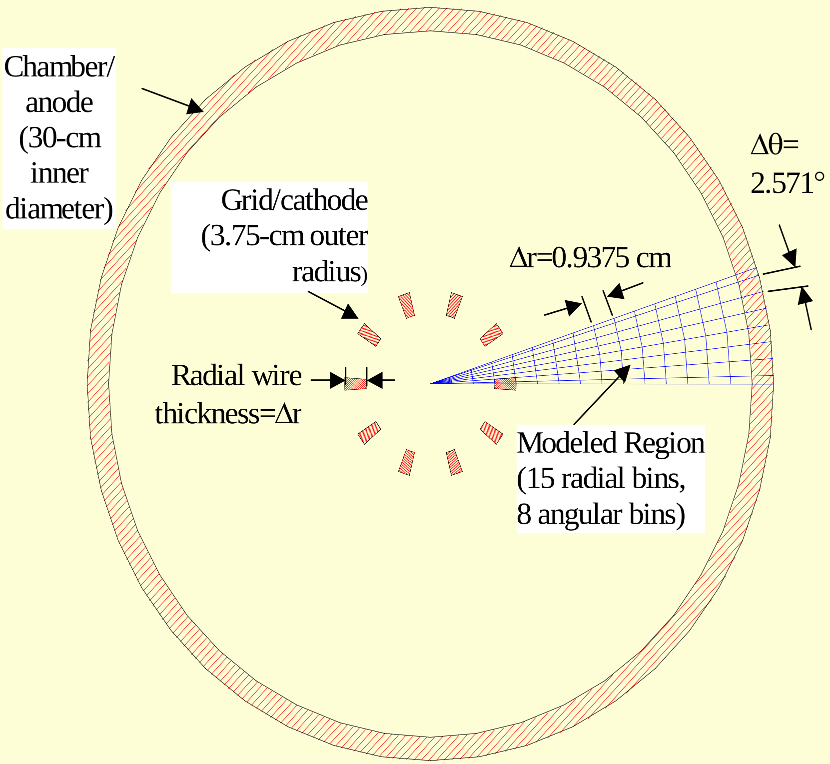
Cathode grid radius	0.075 m
Cathode grid potential	-25 kV
Total ion/electron current inside the grid	59 A/50 A
Ion/Electron injection energy:	19 keV/ 3 eV
Ion/electron energy spread	0.1 eV/ 3 eV
Ion/electron perpendicular energy spread	3 keV/ 3 eV
Recirculation factor	10

Mathematical model and numerical calculation of neutron yields

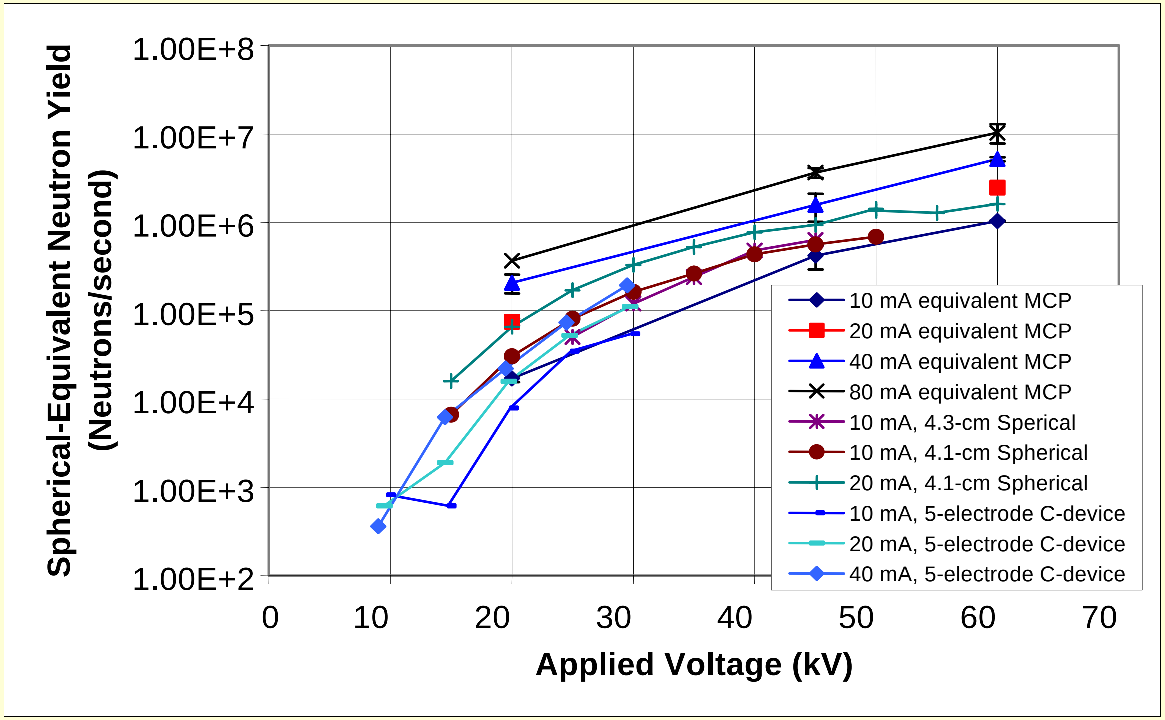
- Mathematic model of C-IEC is used to evaluate scale-up yields required for security applications.

- A Monte Carlo method (MCP code) is selected to self-consistently model detailed geometry and various species (cf. R. Stubbers, UI)
  - Time-independent.
  - Spatially 2-demensional (r and θ) with 3 dimensions in energy and direction.

Cross Sectional Diagram of the RC-IEC Device Modeled by MCP



MCP Calculations of D-D Neutron Yield with Cylindrical Device



- Inspection station goal = 10^8 D-D n/s; projection at 80kV and 0.12A – i.e. ~ 10 kW input..
- Lower power possible with optimized well per prior EIXL calculations.

Tunable x-ray source concept
(cf. Y. Gu, UI)

- It operates at a much lower electron energy (10's to 100 keV compared with >200 MeV in a synchrotron), and still gives a same radiated x-ray energy compensated by a bending radius of much smaller scale from electron-electron interactions
- Intense emission is concentrated in a small volume surrounding the central axis due to the high electron density formed there.
- The resulting x-ray energy spectrum is peaked at an energy about two-thirds of the applied voltage. A voltage around 120 kV will be employed to obtain ~80-kV x-rays.
- Like SIEC, the cylindrical IEC can be converted to an attractive tunable x-ray source with minimum alteration of the apparatus.

SIEC tunable x-ray source

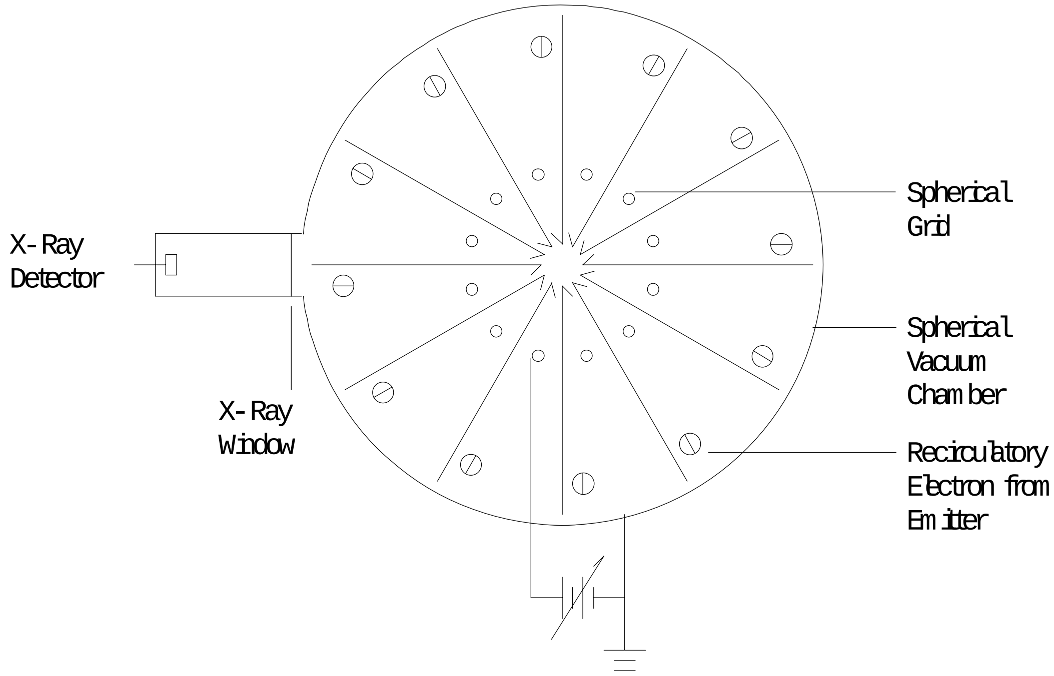


Fig. 4 Spherical IEC tunable x-ray source concept

Unique and attractive features of IEC as tunable x-ray source

- Generating x-rays using relatively low-energy electrons.
- Compactness, relatively low cost, tunability, and high photon energy operation.
- By varying the electron pulse energy in a pulsed mode, chirped x-ray pulses may be generated.
- Thus, the relatively low cost and compactness of IEC can make it more readily available to users.
- The unique x-ray energy spectrum, combined with x-ray production over a long line- like region in IEC provides broad area coverage for the x-ray imaging, consistent with the broad coverage neutron sources.

Security Inspection System

- Inspection devices:

  Array of *neutron* generators: C-IEC

  Array of *x-ray* generators: C-IEC

  Array of detectors: NaI(T1), HgI_2 (cf. L. Meng, UI) etc.

- Techniques: TNA, FNA/PFNA & X-Ray

- Fuzzy logic control: optimize imaging quality and responding time, reduce “false” alarms

Schematic Layout for Combined NAA/X-ray IEC System to Reduce False Signals. Second Line to Left Uses Neutrons from That Side of IECs. Shielding Used to Protect Operators, But Not Shown.

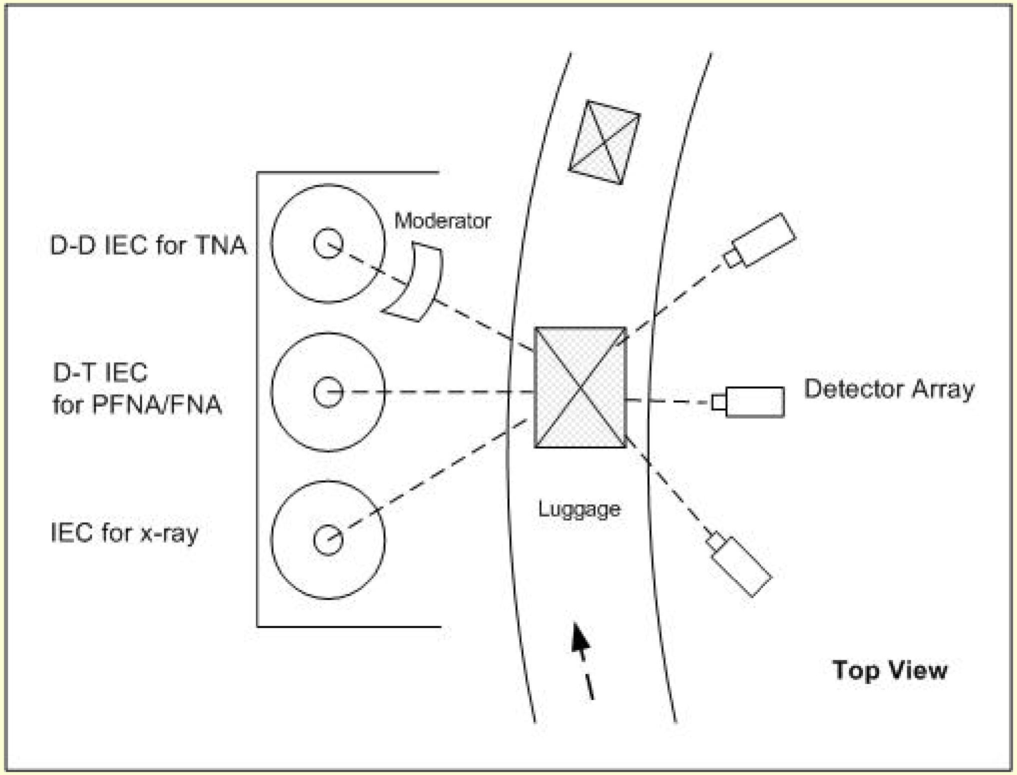


Fig.5a Schematic layout of Inspection System

Cont.

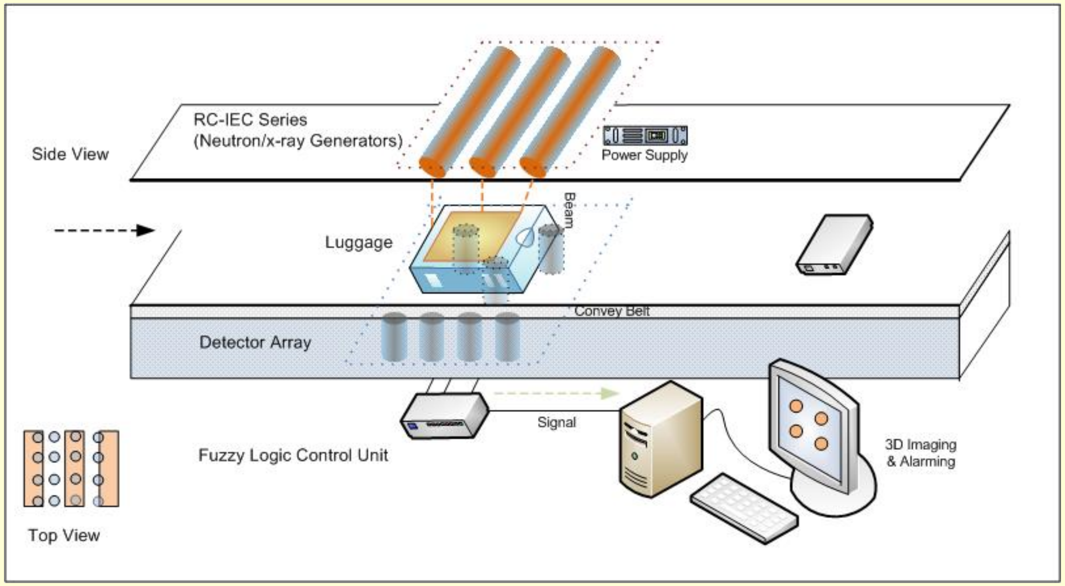


Fig. 5b Further illustration of the integrated system for airport luggage inspection. If desired, a second belt and detector array could be located above the IEC units to provide increased capacity.

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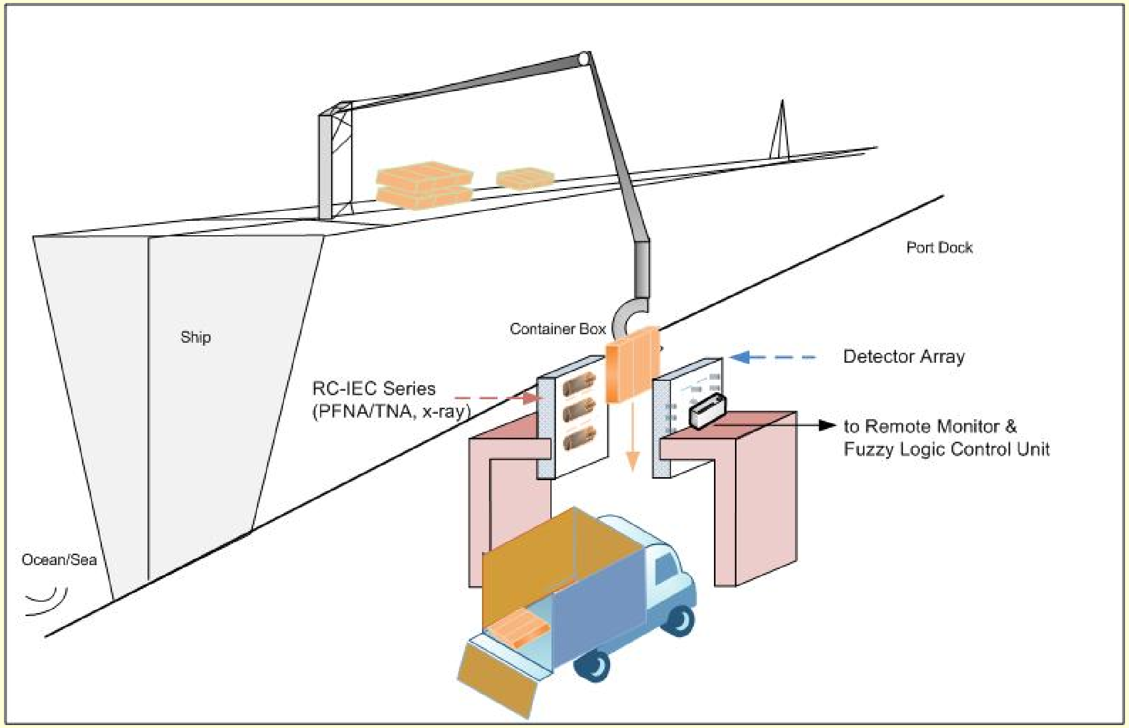
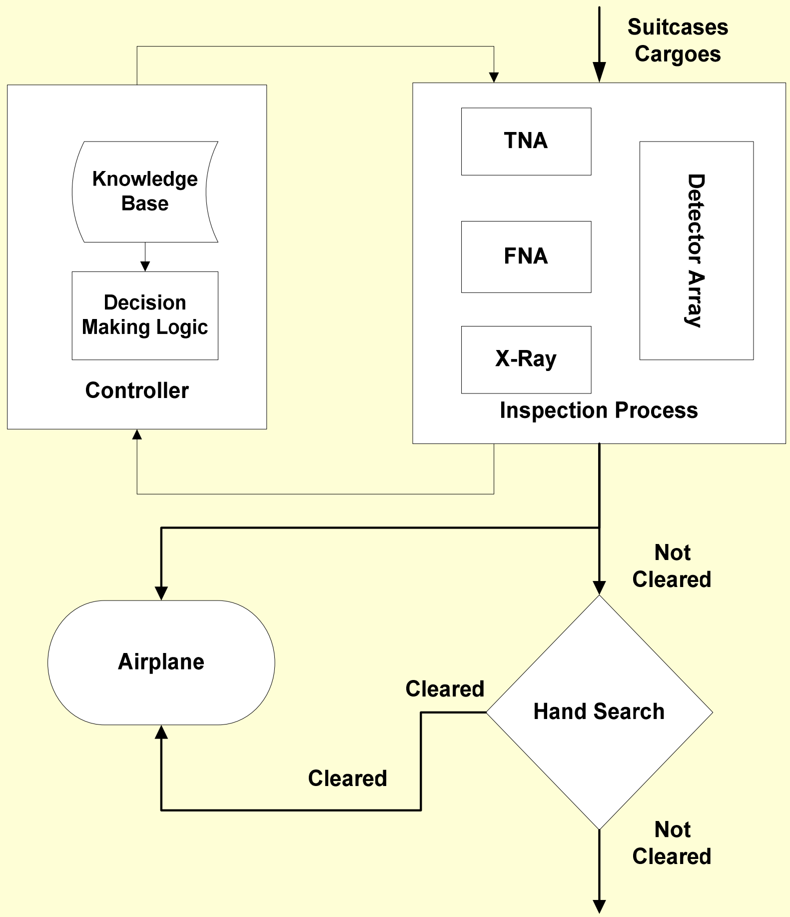


Fig. 5c Further illustration of the integrated system for ship container inspection

Fuzzy Logic Control Used to Analyze Combined Detector Signals. Once "Trained", This Approach Greatly Reduces False Signals.



Conclusion and Discussion

- *Simple configuration, easy operation and reliable neutron production of IEC devices represent an attractive neutron source for NAA-based security inspection system.*
- *The C-IEC is a unique neutron source in providing a line source configuration for ease of broad coverage.*
- *Combined NAA/x-ray IEC system used to reduce "false" signals. A unique fuzzy logic system is recommended for combination of TNA/FNA and X-ray techniques to allow fast inspection while minimizing "false" alarms.*
- *Computations suggest scale-up of present lab devices should achieve satisfactory yields/efficiencies.*

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