Maritime Radiological Search Operations

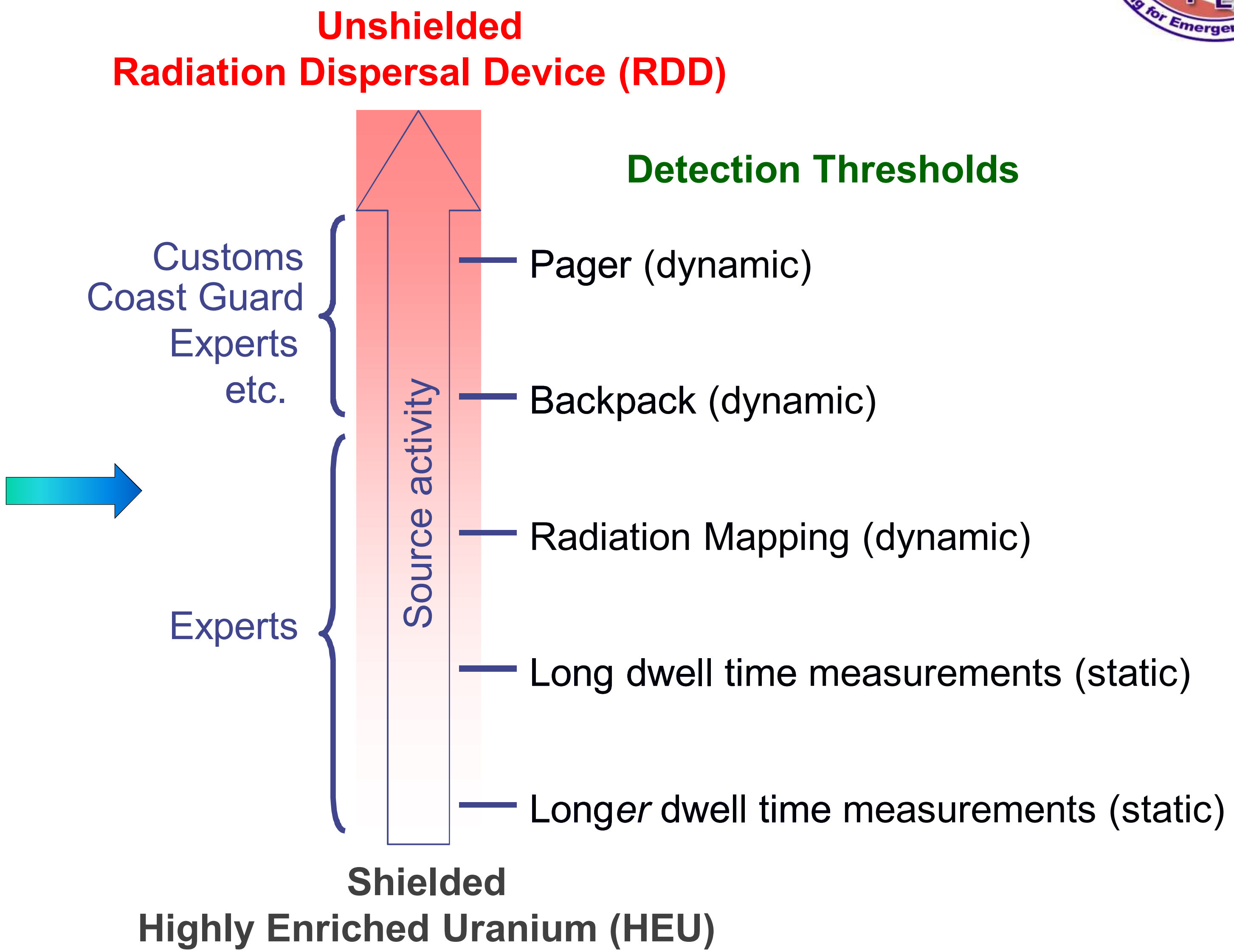
What is the Threat?

A lost or stolen industrial gamma source is the most likely concern for a radiological threat, but Special Nuclear Materials have the highest potential for significant consequences

Occurrence	Probability	Source	Activities / Consequences	Probability	Detectability
Most likely		*Industrial gamma – Cs-137, Co-60, Ir-192, Sr-90*	*Medium to high activities* *Consequences high*		**Highest**
		Medical gamma – Tc-99m, Tl-201, I-131	*Low activities* *Consequences low*		
		Industrial neutron – Cf-252, AmBe, RaBe, AmLi	*Low to medium activities* *Consequences low*		
		Naturally Occurring Radioactive Materials (NORM) - K-40, U-238, Th-232 and decay products	*Very low activities* *Consequences low*		
Least likely		Special Nuclear Materials (SNM) - U-235, Pu-239	*Very low activities* *Consequences highest*		**Lowest**

Maritime Search Operations

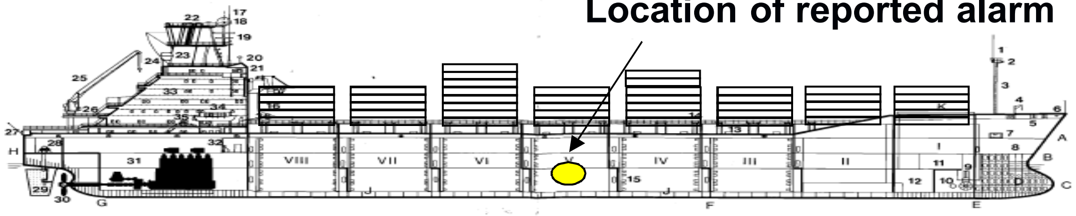
Where is shielded plutonium on this scale?



Maritime Search Missions

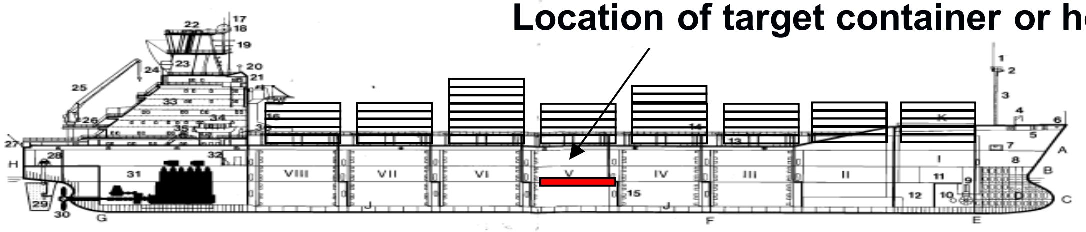
1. **Confirm, identify and characterize an alarm found by initial boarding security team**

Location of reported alarm



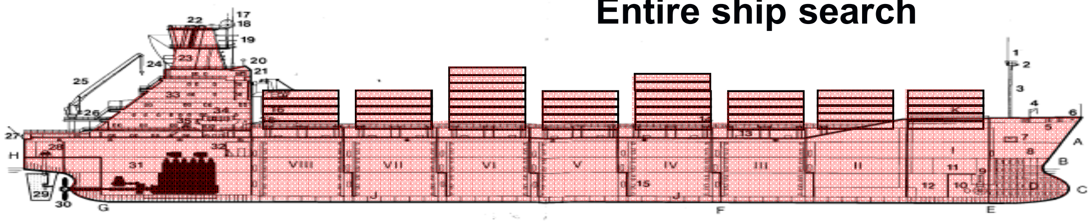
2. **Search a targeted container, group of containers or hold identified by intelligence**

Location of target container or hold



3. **Search and clear an entire ship with no alarms found by initial boarding team**

Entire ship search



Increasing difficulty and time

What is the Ship Effect?

The neutron background on or near a large ship is very unique and attributed to cosmic-ray interactions in the ship's steel and cargo. This effect has become known as the ***Ship Effect.***

Maritime Response Teams approaching or boarding a ship with a neutron detector may interpret elevated neutron count rates as a malevolent neutron source, when in fact:

1. Approaching a ship with a neutron detector may show an increase in neutron count rates attributed to the ***Ship Effect*****.**
2. Elevated neutron readings on a ship near superstructures and very dense cargo could be attributed to the ***Ship Effect.***

As a responder, you must be aware of these two factors when approaching or conducting a radiation search of a ship

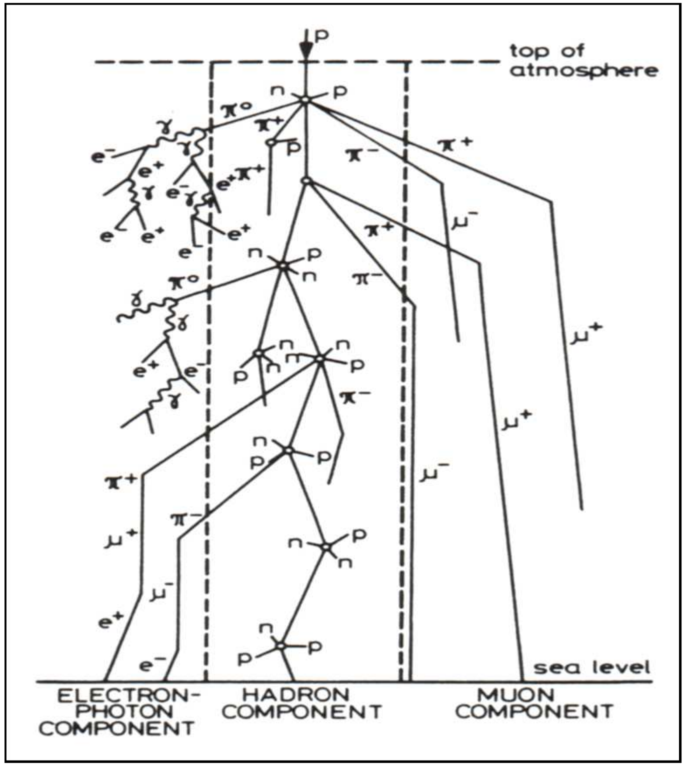
Current Understanding

The Ship Effect has been well studied on approach and aboard a ship with a variety of radiation detection instrumentation, cargo and ship types. These studies resulted in the development of specialized instrumentation to assist Maritime Response Teams in discerning between ship effect neutrons and those from a malevolent neutron source.

To a detector, a ship looks like a low intensity neutron source

What causes the Ship Effect?

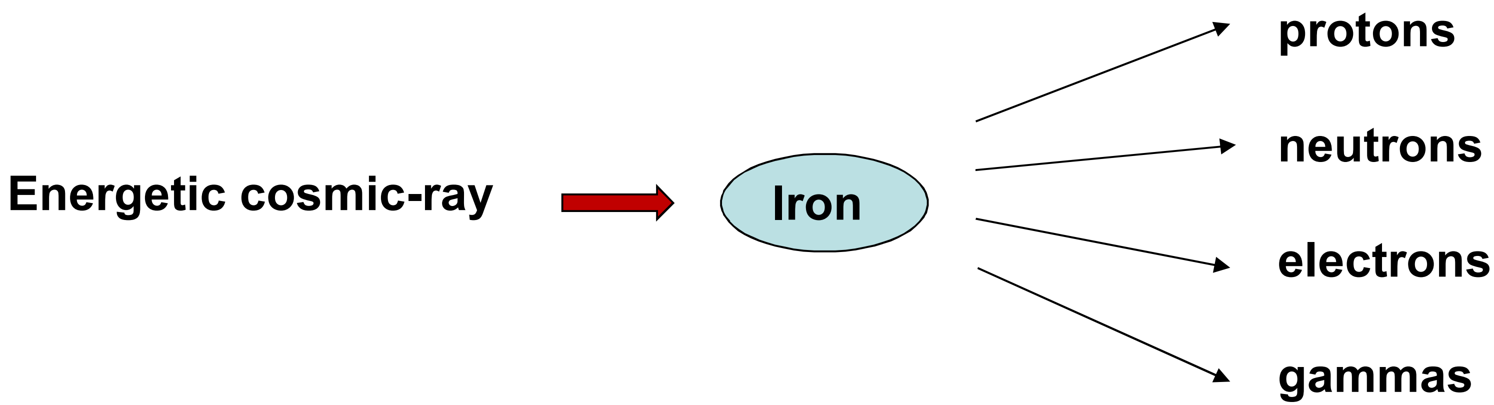
- **The Ship Effect is caused by cosmic-rays:**
  - Cosmic-rays consist primarily of highly-energetic protons originating outside our solar system
  - Most interact in the upper atmosphere producing a cascading shower of nuclear particles (electrons, muons, neutrons, protons, etc.) toward the earth's surface
  - These very energetic particles penetrate the earth's atmosphere and interact with the ship's steel and dense cargo producing "background" neutrons



Cosmic-Ray Distribution - Protons (90%), He ions (9%), heavier ions (1%)

Cosmic-Rays and Iron

Energetic cosmic-rays and their cascading particles interact with iron in a ship in a process call ***spallation***. Spallation is a violent interaction that essentially causes the nucleus of the iron atom to disintegrate. The disintegration results in the production of neutrons, protons, muons, electrons and gamma-rays. The spallation interaction occurs in less than a nanosecond (10^{-9} s).



Each spallation interaction produces a large number of neutrons or neutron multiplicity which provides a unique signature of a cosmic-ray interaction

Radiation Environment on a Ship

Cosmic-ray spallation "Neutron Ship Effect"

Industrial sources

Contaminated materials

Orphan sources

NORM
TENORM

Radionuclide impurities

Sources of gamma and neutron radiation on a cargo ship

Cosmic-ray spallation in the ship's steel and dense cargo
NORM (Naturally Occurring Radioactive Materials) U, Th, K in products
TENORM (Technologically-Enhanced NORM) U and Th in products
Radionuclide impurities in ship and container steel – U, Th, K, Cs
Industrial radiation sources in commerce – Cs, Co, Ir, Ra, AmBe
Contaminated metals and bulk materials – Co, Cs
Discarded orphan sources in scrap metals – Co, Cs, Ra, AmBe

Neutron Source Reference

Plutonium Metals

^{238}Pu	2,600,000 n/s/kg
^{239}Pu	22
^{240}Pu	1,000,000
^{241}Pu	49
^{242}Pu	1,700,000
WGPu	54,000

Plutonium Compounds

$^{239}PuF_6$	7,300,000 n/s/kg
$^{239}PuF_4$	4,300,000
$^{238}PuO_2$	14,000,000

Uranium Metals

^{232}U	0.004 n/s/kg
^{233}U	1.2
^{234}U	5
^{235}U	0.3
^{238}U	14
HEU	1.2

Uranium Compounds

$^{238}UF_6$	5800 n/s/kg
$^{238}UO_2$	30
$^{235}UO_2$	91000

Composites

$^{210}PoBe$	3,600,000 n/s/g
$^{238}PuBe$	2,300,000
$^{241}AmBe$	2,200,000
$^{239}PuBe$	1,000,000
$^{226}RaBe$	4,000,000
$^{241}AmLi$	3,500,000

Californium

^{252}Cf	2.3×10^{12} n/s/g (4600 n/s/μCi)

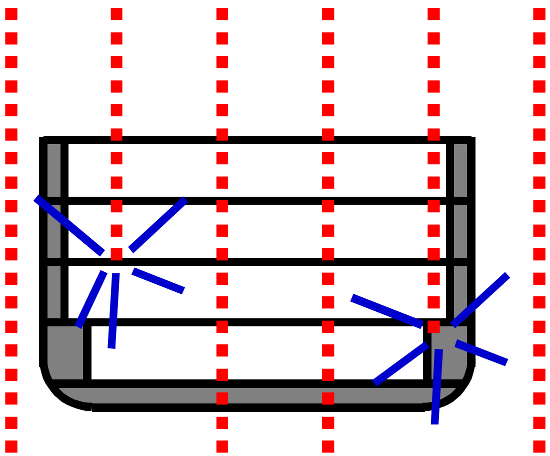
Industrial neutron sources typically emit 100,000 (10^5) to 1,000,000 (10^6) n/s

Neutron sources that emit > 1,000,000 n/s are relatively easy to detect
Neutron sources that emit < 100,000 n/s are hard to detect

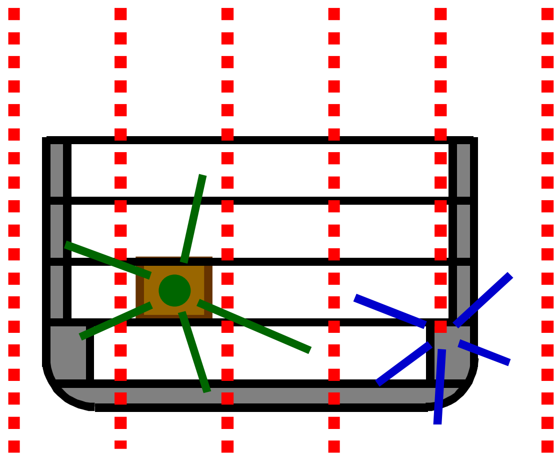
Plutonium Problem

- Neutrons are produced when cosmic-rays interact with a ship's iron
- Neutrons are produced from plutonium via spontaneous fission

→ Very difficult to distinguish cosmic-ray produced neutrons from plutonium spontaneous fission neutrons



Ship with background neutrons only



Ship with background neutrons and plutonium neutrons

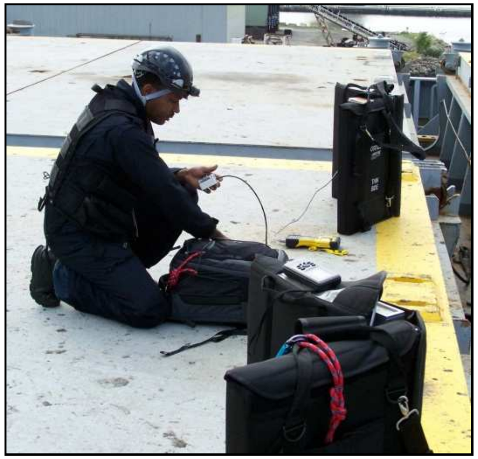
Overview of Maritime Operations

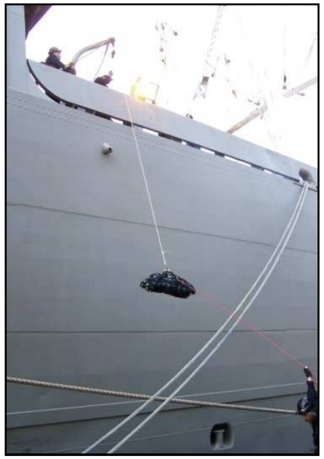
Radiological search and characterization in the maritime environment

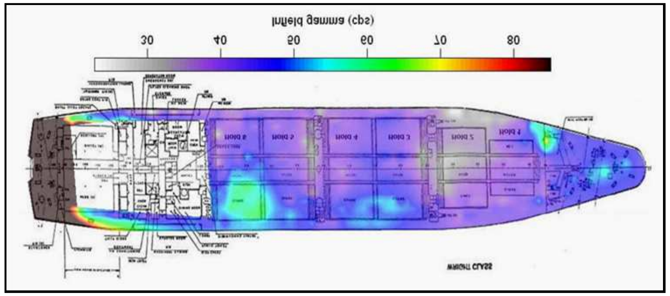
- **Team**
  - **Five person team (minimum)**
  - **Specialized equipment**
  - **Satellite communications**

- **Missions**
  - **Targeted container**
  - **Targeted hold**
  - **Full ship search**

- **Measurements**
  - **Gamma/neutron search**
  - **Long dwell neutron**
  - **Long dwell gamma**
  - **Radiation spatial mapping**
  - **Characterization**







Radiation Pager

Compact detector for locating and pinpointing a radiation source

- **Detectors**
  - **Gamma only**
  - **Gamma/neutron**
  - **Low sensitivity**
- **Unit Dimensions**
  - **0.2 kg**
  - **10 cm L x 5 cm W x 2 cm H**
  - **2 AA batteries**
- **Uses**
  - **Close in radiation monitoring**
  - **Source localization/pinpointing**
  - **Portal monitoring**

Backpack Radiation Detector

Low profile, high efficiency radiation detector for large area search

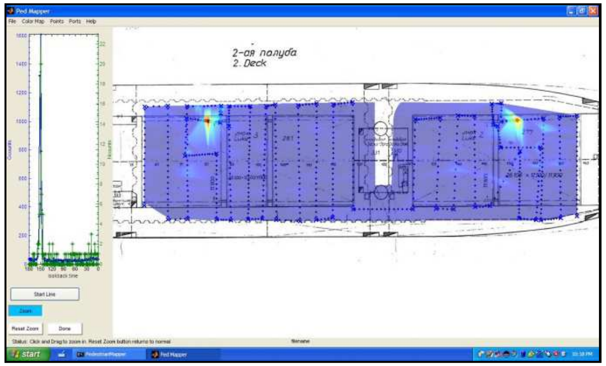
- **Detectors**
  - Gamma and neutron
  - High sensitivity

- **Unit Dimensions**
  - 9 kg
  - 45 cm L x 20 cm W x 45 cm H
  - Rechargeable battery

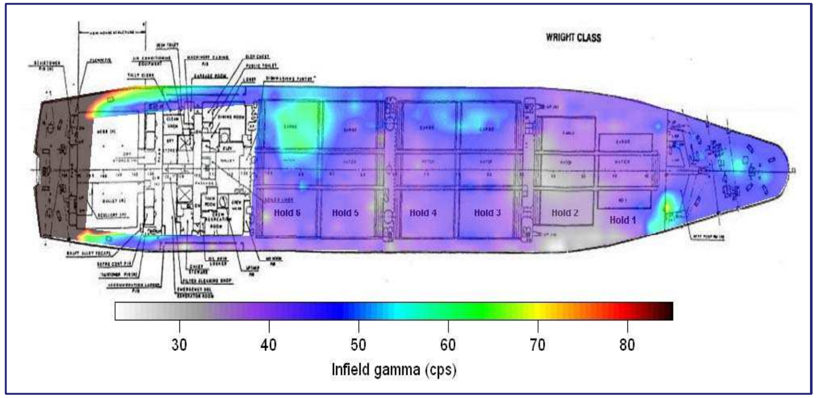
- **Uses**
  - Large area pedestrian search
  - Large area background survey
  - Portal monitoring

Backpack Radiation Mapper

High sensitivity spatial maps for radiological search



- **Detectors**
  - **Gamma and neutron**
  - **Enhanced sensitivity**
- **Unit Dimensions**
  - **9 kg**
  - **45 cm L x 20 cm W x 45 cm H**
  - **Rechargeable battery**
  - **Integrated laptop computer**
- **Uses**
  - **Large area pedestrian mapping**
  - **Search buildings, aircraft or ships**
  - **Localization of hotspots**



Linear Radiation Monitor (LRM)

Backpack or extendable for long length detection applications

- **Detectors**
  - **Gamma and neutron**
  - **Extendable to 24 m length**
- **Unit Dimensions**
  - **3.2 kg**
  - **70 cm L x 20 cm W x 20 cm H**
  - **One 3 volt lithium battery**
- **Uses**
  - **Lower between containers on ships**
  - **Backpack search**

Radioisotope Identifier (RIID)

Low resolution spectrometer for screening radioactive materials

- **Detectors**
  - **Gamma and neutron**
  - **Low sensitivity**

- **Unit Dimensions**
  - **1.4 kg**
  - **30 cm L x 9 cm W x 6 cm H**
  - **4 AA batteries**

- **Uses**
  - **Low resolution identification**
  - **Localization**
  - **Pinpointing**

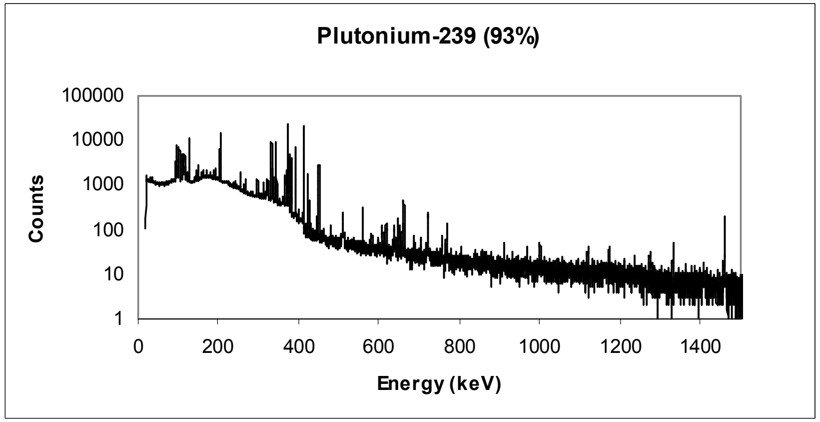
Radionuclide Identification

High resolution gamma-ray spectroscopy

- **Detectors**
  - Gamma and neutron
  - Mechanically-cooled
  - Collimator for aiming

- **Unit dimensions**
  - 12 kg
  - 37 cm L x 17 cm W x 34 cm H
  - Rechargeable battery

- **Uses**
  - Radioactive material identification
  - Radionuclide isotopics
  - Activity quantification

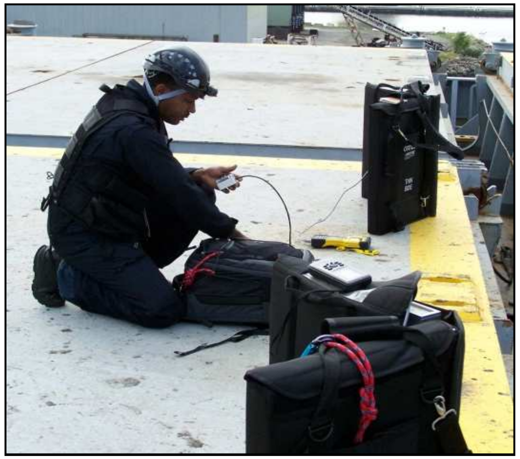


Fission Meter

Assessment of neutrons from fission source versus cosmic-rays

- **Detectors**
  - **Neutron only**
  - **Two panels for high sensitivity**
  - **Thick side 2.5 cm moderator**
  - **Thin side no moderator**

- **Unit dimensions**
  - **26 kg**
  - **47 cm L x 15 cm W x 66 cm H**
  - **8 D-cell batteries per panel**



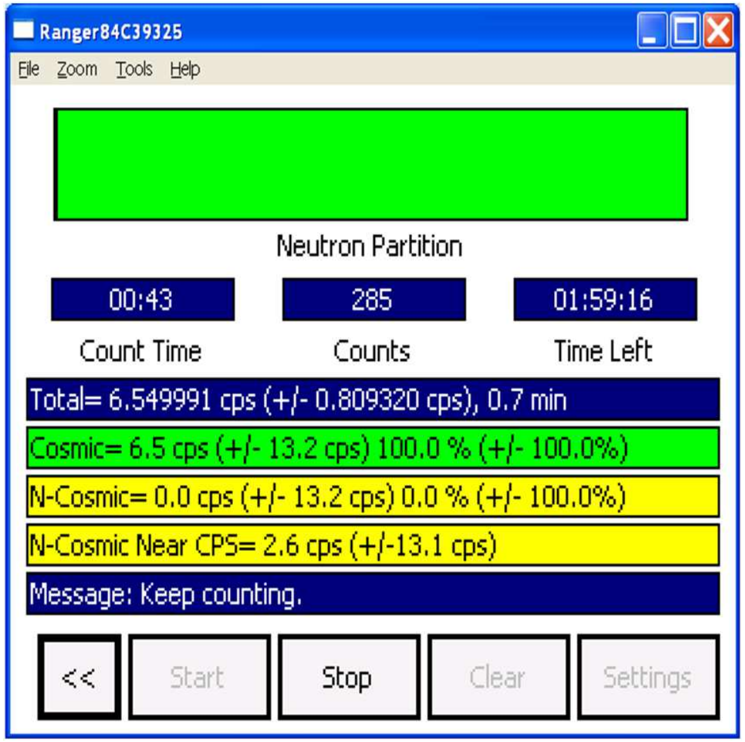
- **Uses**
  - **Ship search**
  - **Characterization of "Ship Effect"**
  - **Radionuclide assay**
  - **Multiplicity counting**

Comparison of Processes

(α,n) Reactions	Nuclear Fission	Cosmic-Ray
➢ The number of neutrons associated with (α,n) reactions is a statistical process and ranges from 0-1 ➢ Occurs in a single interaction over a very short time period (less than 1 nsec) ➢ The neutrons are not correlated in time and random	➢ The number of neutrons associated with nuclear fission is a statistical process and ranges from 0-7 ➢ Occurs in a single decay over a very short time period (less than 1 nsec) ➢ The neutrons are correlated in time and not random	➢ The number of neutrons associated with cosmic-ray interactions is a statistical process and ranges from 0-50 ➢ Occurs in a single interaction over a very short time period (less than 1 nsec) ➢ The neutrons are correlated in time and not random

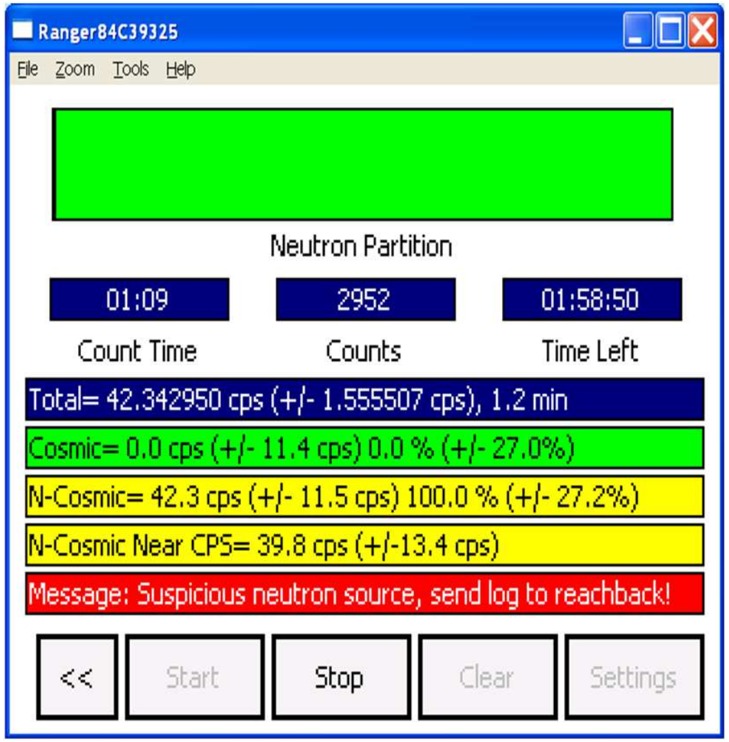
The Fission Meter can measure the differences in neutron distributions

Static Search Mode



Quick Look Display

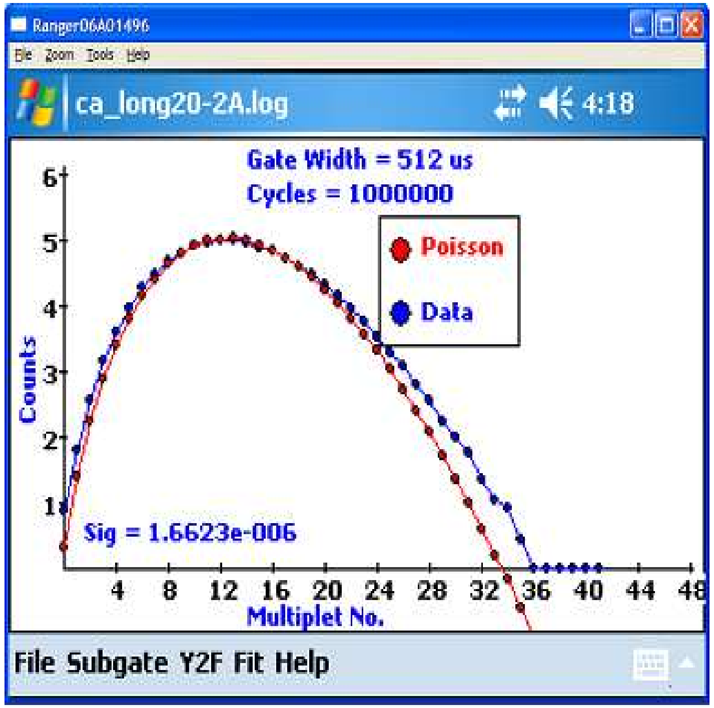
Routine Cosmic-Ray Background



Quick Look Display

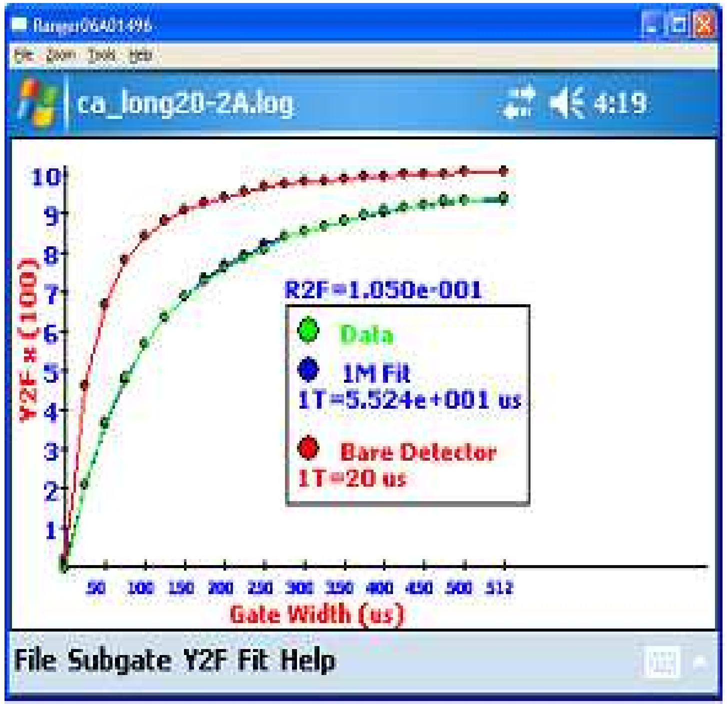
Source Alarm

Characterization Mode



GraphIt Quick Look Display

Neutron Distribution Plot



FIT Quick Look Display

Neutron Lifetime Plot

Further analysis of the Characterization Data requires sending the data to the DOE Triage System

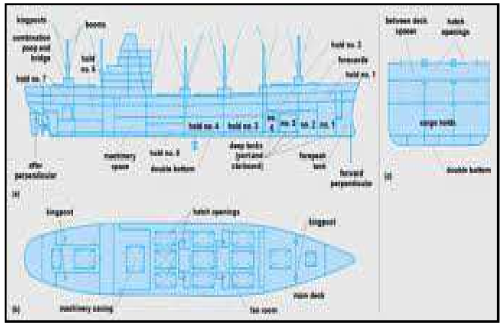
Maritime Concept of Operations

Develop a maritime search plan and estimate completion time
Deploy team and equipment to port staging location
Transit to and board ship
Obtain common operating picture and situational awareness
Review security boarding team radiation search process and equipment
Determine which container(s) or hold(s) to search
Move to working point
Investigate radiation anomalies
Respond to new anomalies
Localize source(s)
Pinpoint hotspot(s)
Characterize hotspot(s)
Review data quality and backup data
Transmit data to scientist or Triage for review
Request further assets if required
Redeploy team

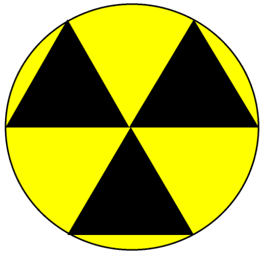

Concept of Operations
Maritime Search

January 2011

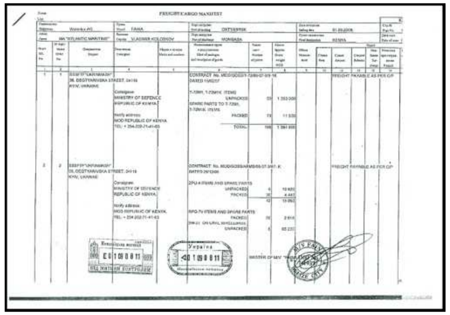
Maritime Search Planning



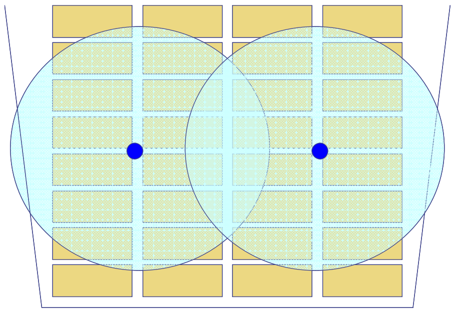
Ship Type
Determine the ship type, size, and number of holds etc. and obtain deck plans



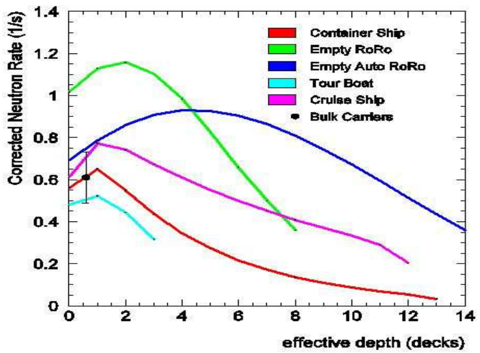
Radiation Source
What is the radioactive material, activity, form etc.



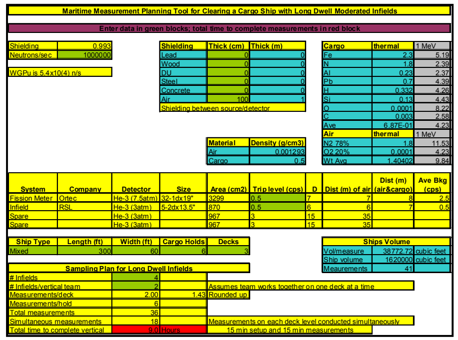
Intelligence
Identify the country of origin, shipper, manifest and load plan



Cargo
Estimate cargo density which affects Field-of-View



Neutron Background
Determine ship's cosmic-ray neutron background



Maritime Search Plan
Incorporate all information into a maritime search plan

Maritime Equipment Suite

Radiation backpacks in dry bags (search/mapping)
Fission meters in dry bags (search/characterization)
HPGe in soft bags (ID/characterization)
Radioisotope identifiers (search/screen/localize)
Gamma/neutron pagers (scan/localize)
Linear Radiation Monitor (search/localize)
Health Physics Kit (contamination survey)
Computer/commo kit (satcom/cellular)
Digital camera (documentation)
Hoisting backpack with rope and winch
Support box with netting, food, water

Multiple boxes, hundreds of kg

Maritime Case Study

Sri Lanka, October 2005

Sri Lanka Incident – October 2005

On October 5, the U.S. Department of Energy, Mega Port Initiative was in the process of installing and testing a portal monitoring system for the monitoring of radiation in shipping containers located in the Port of Colombo, Sri Lanka. During the process of performing the setup, 17 containers were scanned without verify the readings. The containers were then loaded on several shipping vessels. The data from the monitor was reviewed after the containers were shipped out. The data showed that there was a neutron signature from one of the 17 containers.

Sri Lanka Incident Deployments

In conjunction with international partners, the U.S. DOE established four maritime teams, sending three of the teams to ports and ships to locate the containers and conduct measurements.

Team 1 – India – not deployed

Team 2 – New York – deployed

Team 3 – Germany – deployed

Team 4 – Halifax – deployed

Case Study - Hamburg, Germany
October 22 to November 1, 2005

The Nedlloyed Oceania

Hamburg, Germany
October 22 to November 1, 2005

DOE team arrived Hamburg, Germany on October 25

Ship entered port on October 28

Joint German-U.S. DOE team transited to the ship via a police boat

Objective was to confirm that the containers would not present a radiological health risk when transferred off the ship

DOE requested additional measurements prior to boarding the vessel

The police boat circled the vessel twice to allow measurements to ensure there was no hazardous radiation prior to transferring the team to the vessel

Getting to the Nedlloyed Oceania

Team was deployed by helicopter limiting equipment suite

Team and gear was then transferred to a police boat

Team and gear was then transferred to a pilot boat to board ship

Arriving at the Nedlloyed Oceania

The team made close passes by the ship with the detection instruments to reassure hosts that any radiation present did not present an immediate threat to life or health. No radiation was detected.

- Team boarded at sea by Jacob's and accommodation ladder
- Acquired static neutron and gamma rate measurements and HPGe spectra
- No source detected
- Team de-boarded through the sea door
- Containers later off-loaded, x-rayed and searched with HPGe and Fission Meter

Equipment Inventory

The U.S. DOE team deployed to the ship with the following equipment:

Backpack detectors
Fission meter detector
HPGe high resolution gamma detector
Radioisotope identifier (RIID)
ADM-300 health physics kit
Camera
Laptop computers and satellite phone
Personal protective clothing

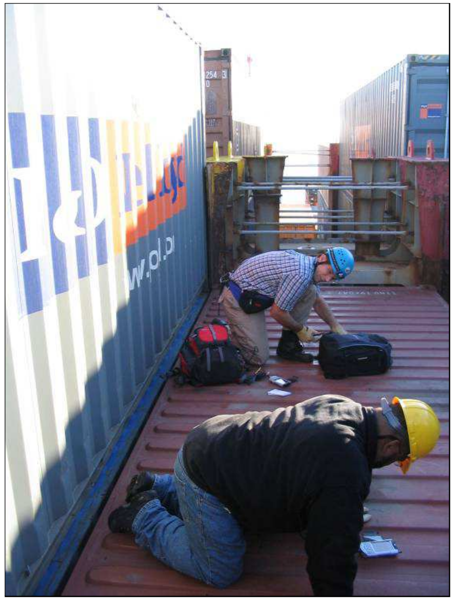
Backpack

Fission Meter

HPGe Detector

RIID

Three Container Measurements



The first container was near the top of the stacks. Thirty minute measurements were made using moderated backpacks and HPGe.

The second container was not easily accessible. Instruments were lowered by rope into the gap between the bulkhead and container stack.

The third container was also very difficult to access. HPGe and static backpack measurements were used at this location.

Measurement Details at Terminal

Container Terminal Altenwerden

October 28, received approval to inspect the three containers from the Nedlloyd Oceania. The containers were removed from the ship.

For each container the following measurements were conducted:

1. A one hour Fission Meter measurement in search mode.
2. A 30 minute 3 MeV HPGe spectrum.
3. A 30 minute 12 MeV HPGe spectrum.

The data from each primary measurement were sent to DOE Triage for further analysis.

Fission Meter Geometry

Upon off-loading, the containers were made available for measurements.

Fission Meter oriented horizontal on boxes below shipping container

Typical Measurement Geometry

Fission Meter

HPGe 3 MeV and 12 MeV

An example of the measurement geometry and the fission meter results for container number PONU0483753:

Measurement duration: 1hr 16 min
Total average rate: 2.275±0.045 n/s
Cosmic rate: 2.3±0.2 n/s (100±3.8%)
Non-Cosmic: 0.0±0.2 n/s (0±3.8%)

Conclusions

- **Measurements were conducted for three containers both on and off the ship**
- **All results negative**
- **German and U.S. teams redeploy**
- **Radiation source ultimately found in container in India. It was reported to be an Americium/Beryllium (AmBe) neutron source mixed with scrap metal.**

Maritime Radiological Search Operations

Questions?