International Symposium on Technology Development for Nuclear Nonproliferation and Nuclear Security

Session1：NDA Technology for Nuclear Safeguards

[Panel Discussion 1] Challenges of Technology Development for Future Safeguards

February 10, 2016

Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN)
Japan atomic Energy Agency (JAEA)

[Panel Discussion1]

Challenges of Technology Development for Future Safeguards

11:20～12:40 (80 minutes)

[60 minutes among the panelists, 20 minutes among all attendees]

Panelists	
Ms. Arden Dougan	Senior Program Manager DOE/NNSA
Mr. Mark Fitzpatrick	Executive Director IISS-America Office
Mr. Mitsuru Uesaka	Professor University of Tokyo
Mr. Peter Schillebeeckx	Scientific Officer EC/JRC-IRMM
Mr. Hirofumi Tomikawa	General Manager JAEA-ISCN
Mr. Michio Seya (Moderator)	Senior Advisor JAEA-ISCN

Panel Discussion 1

Arden Dougan

Mitsuru Uesaka

Mark Fitzpatrick

Challenges of Technology Development for Future Safeguards

Peter Schillebeeckx

Michio Seya
(Chair)

Hirofumi Tomikawa

Panelist	Title, Affiliation, Research Area
Dr. **Arden Dougan**	Senior Program Manager Office of Proliferation Detection Defense Nuclear Nonproliferation Research and Development National Nuclear Security Administration U.S. Department of Energy Long term R&D for Safeguards, Warhead Verification and Monitoring and Radiological Source Replacement
Mr. **Mark Fitzpatrick**	International Institute for Strategic Studies (IISS) - Executive Director, IISS-Americas office - Head of IISS Non-Proliferation and Disarmament Programme Joined IISS in October 2005 after a 26-year career in the US Department of State, including as Deputy Assistant Secretary for Non-Proliferation (acting) Research focus on countries and areas of proliferation concern, especially North Korea, Iran, South Asia. New book on 'Asia's Latent Nuclear Powers: Japan, South Korea and Taiwan'

Panelist	Title, Affiliation, Research Area
Professor Mitsuru Uesaka	Ph.D. Professor / Nuclear Professional School School of Engineering University of Tokyo -compact electron linac development for cancer therapy -nondestructive testing / nuclear security -laser photonic crystal accelerator for DNA damage -repair analysis in radiation biology -X-band linac-based compact short-pulsed neutron source
Dr. Peter Schillebeeckx	Scientific Officer European Commission/Joint Research Centre Geel site -Responsible for neutron cross-section measurements at the time-of-flight facility GELINA -Evaluation of cross section data for nuclear energy applications including production of covariance data -Non-destructive analysis techniques -Neutron detection techniques

Panelist	Title, Affiliation, Research Area
Mr. Hirofumi Tomikawa	General Manager Technology Development Promotion Office Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN) Japan Atomic Energy Agency (JAEA) -R&D Management for CTBT / Nuclear Forensics / Proliferation Resistance / Nuclear Safeguards / Nuclear Security
Mr. Michio Seya	Senior Advisor Technology Development Promotion Office Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN) Japan Atomic Energy Agency (JAEA) -R&D Management on Advanced Technologies for Nuclear Detection and Measurement

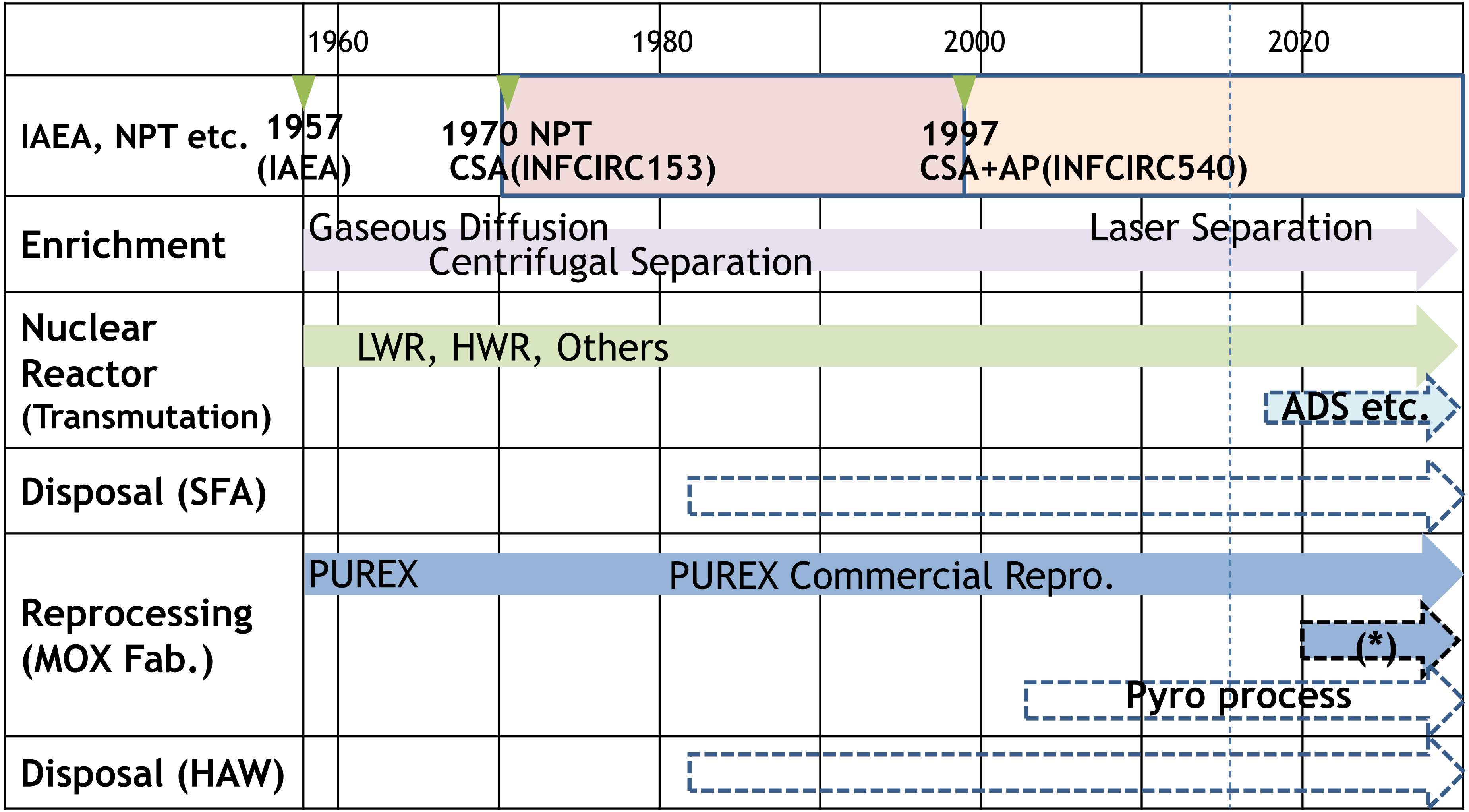
Introduction to Panel Discussion
“Challenges of Technology Development for Future Safeguards”

by Michio Seya

Safeguards in the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

Peaceful Use of Nuclear Energy

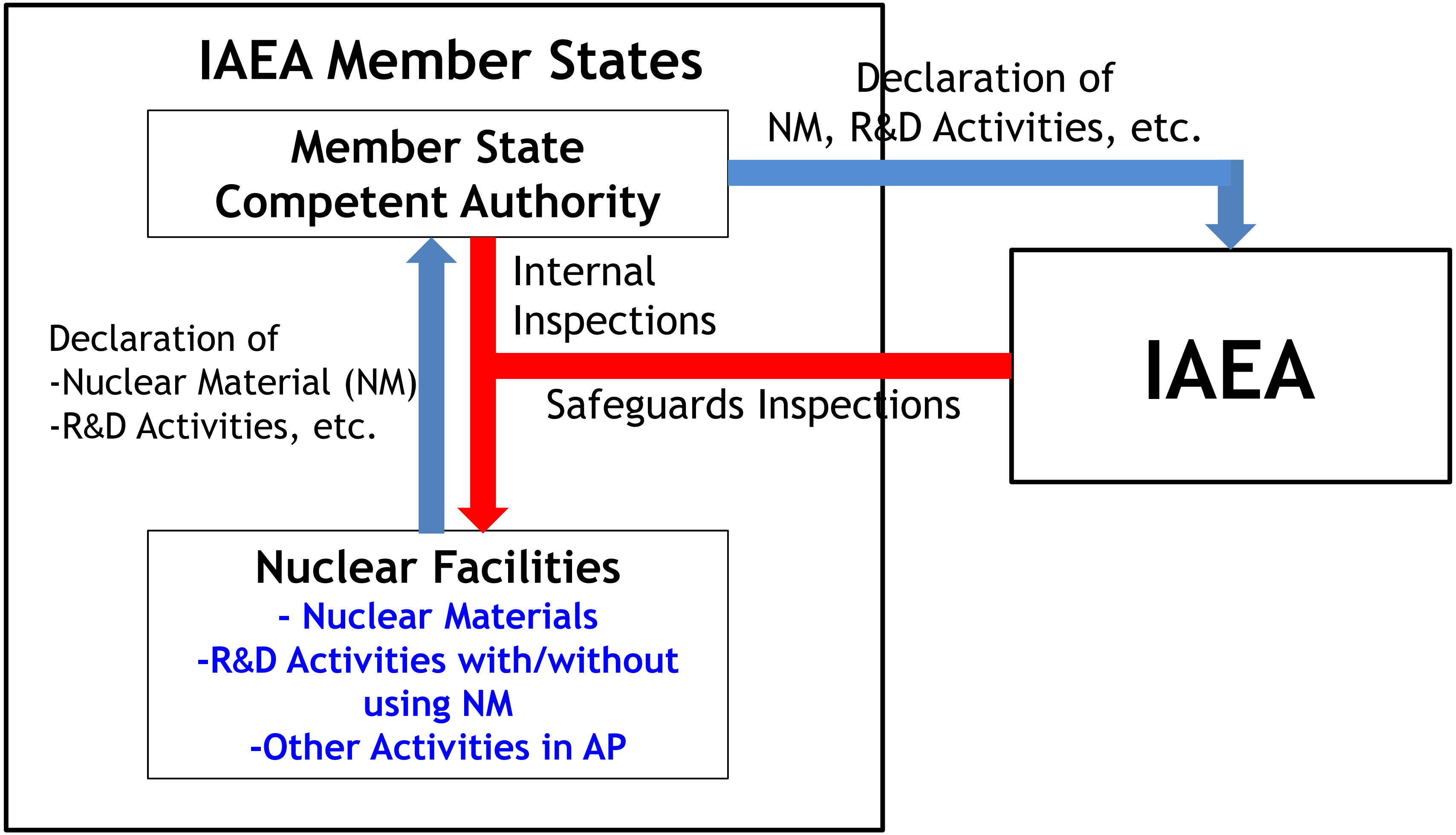
CSA: Comprehensive Safeguards Agreement, AP: Additional Protocol



ADS: Accelerator Driven System, **(*)PUREX-base TRU recovery + MOX Fab.**

IAEA Safeguards (CSA + AP)

CSA: Comprehensive Safeguards Agreement, AP: Additional Protocol



IAEA Safeguards Inspection Activities

CSA Base Inspection Activities		
Purpose	**Verification Methods**	
Bias defect checking (precise analysis)	By confirmation of isotopic compositions / quantities of NMs	DA (Destructive Assay)
Partial defect checking (with accuracy of several %)	By confirmation of isotopic compositions / quantities of NMs	NDA (Non-Destructive Assay)
Gross defect checking (with attribute test)	By confirmation of attributes	
Continuity of knowledge (Reduction of Re-verification)	By monitoring	C/S (Containment /Surveillance)

AP Base Inspection Activities (Complementary Access (CA))		
Purpose	**CA Activities**	**Methods**
Detection of undeclared NM (isotopic compositions/ quantities) Detection of undeclared R&D Activities, etc.	Collection of Environmental Samples	DA of Environmental Samples
	Radiation Detection and Measurement	Portable NDA
	Checking of existence signals of NM (For supporting effective sampling at the access place)	Portable NDA
Detection of Undeclared Facility	Visual Observation Measurement by Laser System, etc.	Analyzing Satellite Imagery, etc.

Integrated Safeguards

［CSA(INFCIRC/153)+AP(INFCIRC/540)］

IAEA

Short Notice Random Inspection

(Timing of Inspection; Important for Effectiveness)

↓

NM in Nuclear Facilities

Application of State Level Approach

Necessity of Support from Member States to IAEA

IAEA: Implementing wide-range activities
CSA + AP Activities
Inspection to Declared Nuclear Material
Complementary Access
Others

IAEA's Requests for Support to Member States

- Support of R&D for Verification Technology

  [STR - 375 IAEA Department of Safeguards Long-Term R&D Plan, 2012-2023 (January 2013)]

  ⇒For strengthening IAEA abilities, improving effectiveness, etc.

- Safeguards by Design for (Large-size) Automated Facilities (Reprocessing Plants (MOX Plants), Nuclear Facilities treating very high radiation NM, etc.)

  ⇒For reduction of PDI (Person Days of Inspection)

(STR-375) IAEA Department of Safeguards Long-Term R&D Plan, 2012-2023 (Extracted Parts)

4-5 items to be concentrated in this discussion among so many IAEA's R&D requests

(STR - 375) IAEA Department of Safeguards
Long-Term R&D Plan, 2012-2023 (January 2013)

3. Ability to safeguard new types of facility. (1/2)	
3.1 Develop generic safeguards approaches for:	
• Pyroprocessing plants	M
• Other new reprocessing technologies	L
• Laser enrichment plants	M
• Other new enrichment technologies	L
• Small modular and/or Gen IV reactors	M
3.2 Develop tools and techniques to characterize:	
• Fissile content in metal mixtures containing the actinides Np, Am and Cm during pyroprocessing	M
• Fuel types for Gen IV reactors containing minor actinides	L
• Seismic signals in geological repositories	M

(STR - 375) IAEA Department of Safeguards
Long-Term R&D Plan, 2012-2023 (January 2013)

3. Ability to safeguard new types of facility. (2/2)	
3.3 Develop training to reflect the approaches and equipment for safeguarding new types of facility, including consulting with States developing such facilities to help assess what training is required.	L
3.4 Develop a mechanism to enable safeguards to be considered early in the facility design process. (Safeguards by Design)	M

(STR - 375) IAEA Department of Safeguards
Long-Term R&D Plan, 2012-2023 (January 2013)

5. Ability to deploy equipment at facilities to meet safeguards requirements. (1/2)	
5.1 Develop improved tools and techniques to detect misuse of reprocessing plants (real time detection of Pu separation)	L
5.2 Develop tools and techniques to enable timely, potentially real time, detection of HEU production in LEU enrichment facilities.	H
5.3 Develop improved tools and techniques to enable real time flow measurements of nuclear material, including UF6 at enrichment facilities and Pu at reprocessing facilities.	M
5.4 Develop appropriate safeguards equipment to establish and maintain knowledge of spent fuel in shielding/storage/transport containers at all points in their life cycle.	M
5.5 Develop methods to verify fresh fuel in shipping containers without opening the containers.	M

(STR - 375) IAEA Department of Safeguards
Long-Term R&D Plan, 2012-2023 (January 2013)

5. Ability to deploy equipment at facilities to meet safeguards requirements. (2/2)	
5.6 Develop improved NDA instruments and techniques to address verification of waste and scrap nuclear material with impure composition or heterogeneous isotopic composition.	M
5.7 Develop more sensitive and less intrusive alternatives to existing NDA instruments to perform partial defect test on spent fuel assembly prior to transfer to difficult to access storage.	H
5.8 Develop alternative NDA instruments, for instance based on liquid scintillators, to improve performance in neutron coincidence counting techniques applied to various types of fissile material.	M

(STR – 375) IAEA Department of Safeguards
Long-Term R&D Plan, 2012-2023 (January 2013)

6. Ability to acquire and deploy safeguards equipment that is sustainable, standardized and modular, with increased use of commercial off-the shelf products	
6.1 Implement an improved cost/benefit assessment methodology for the design and operation of safeguards equipment	M
6.2 Develop neutron counting systems reducing the use of ^{3}He or offering equivalent functional and technical alternatives	M

Safeguards by Design ("SBD") for (Large Size) Automated Nuclear Facilities

-Reprocessing Plants, MOX Plants
-New Types of Nuclear Facilities
  (treating very high radiation NM)
    *Next Generation Aqueous-base
                    Reprocessing Facilities
    *Pyro processing facilities
    *Transmutation fuel (ADS fuel) facilities

"SBD" Process for Effective SG Verification of NM in Process

In (large size) automated nuclear facilities treating NM with very high radiation, people (operators/inspectors) can not go inside the process area. For this kind of facility, it is necessary to integrate SG verification systems into facility operation systems.

"SBD" Process

Well Demonstrated Safeguards Systems for Practical Use

(to be developed in advance of design of nuclear facility)

↓

Safeguards Systems ; Properly / effectively integrated into systems (such as transfer system) of nuclear facilities

↓

-Reduction of PDI (Person-Days of Inspection)

-Reduction of Operation Interference by Inspection

Items of Panel Discussion 1 ”Challenges of Technology Development for Future Safeguards”

i	Support of R&D for NDA in Verification Technologies (1/2)	
	1	Development of Neutron Counting Systems using Alternative Detectors to ^{3}He
	2	Innovative R&Ds for Improvement of Present SG Equipment
	3	NDA Techniques / Systems for LWR Spent Fuel Assemblies
ii	Safeguards by Design “SBD” for (Large Size) Automated Nuclear Facilities	
	4	Safeguards by Design “SBD” for Nuclear Facilities
iii	Support of R&D for NDA in Verification Technologies (2/2)	
	5	Development of NDA Technologies for Pu, Am, Np, Cm in Mixtures

End of Introduction

Items of Panel Discussion 1
”Challenges of Technology Development for Future Safeguards”

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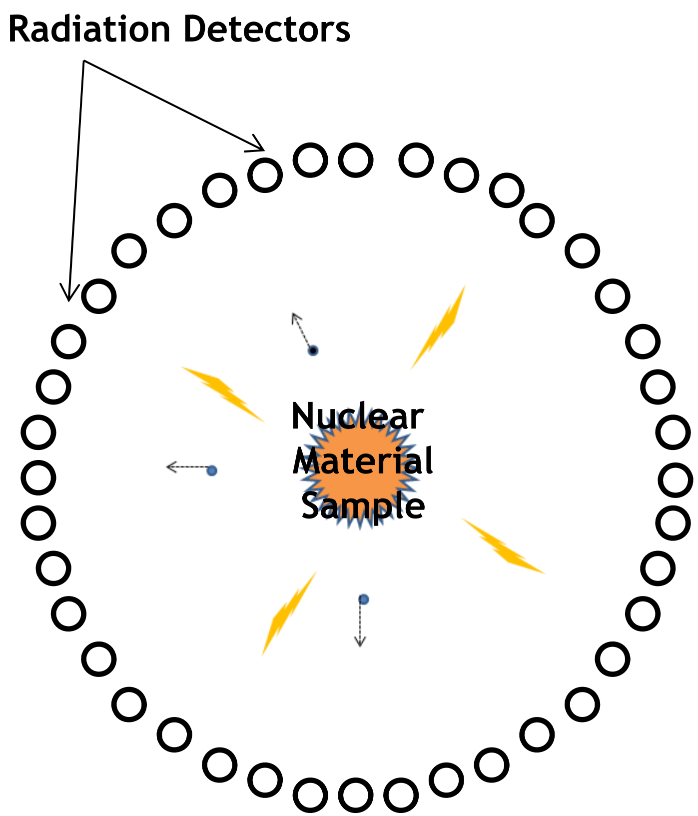
NDA Technologies in Safeguards

Categorization of NDA Types	Rough Explanation
Passive Type	Detection of self-emitted radiations from NM
Active Type	Using outer sources of radiation to activate NM Detection of induced / transmitted radiations (changes of radiations)

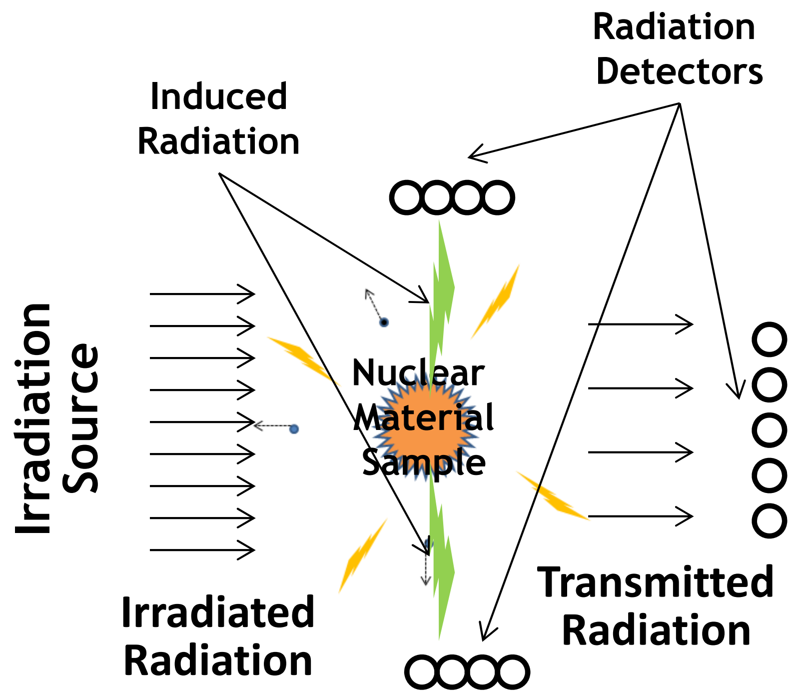
Passive Type and Active Type NDA in SG Verification

Passive Type NDA



Detecting self-emitted radiations from NM

Active Type NDA



Detecting induced/transmitted radiations
(Detecting changes of radiations)

Items of Panel Discussion 1 "Challenges of Technology Development for Future Safeguards"

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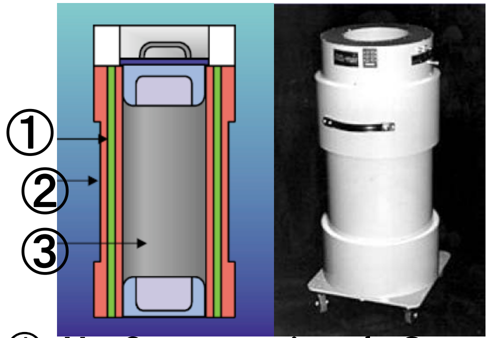
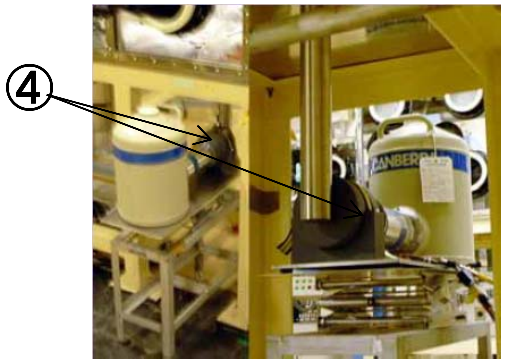
Passive Type NDA in SG Verification (Neutron Coincidence Counter)

Rough Explanation of Principle
Using self-emitted neutrons: -Spontaneous fission neutrons from ^{238}Pu, ^{240}Pu, ^{242}Pu etc. -Count neutrons emitted from the same spontaneous fission **(→quantification of ^{240}Pu-eff. in the sample)**
Neutron Detectors: ^{3}He proportional counter
Usage in Nuclear Fuel Cycle
Partial Defect Verification of purified Pu from PUREX process etc. Nuclear facilities; Conversion process of reprocessing plant / facility MOX fabrication plant / facility

-Concern with shortage of ^{3}He gas supply（2009～）

-IAEA requested member states for development of alternative detectors to ^{3}He (March, 2011)

(Example) Neutron Coincidence Counters at Reprocessing Plants / MOX Plants

	Pu Nitrate Solution / MOX Samples (Purified Pu, U: Containing no FP/MA)	
	Present SG Verification	
Pu Quantity (^{240}Pu-effective)	NDA (Passive type NDA) - HLNCC / INVS [High Level Neutron Coincidence Counter / Inventory Sample Counter] ＊Counting of Spontaneous Fission Neutrons from ^{240}Pu etc.	HLNCC  ①: He-3 proportional Counter ②: Polyethylene ③: Sample Cavity
Pu Isotopic Compositions	NDA (Passive type NDA) - HRGS [High Resolution Gamma-ray Spectrometer] ＊Counting of Self-emission Gamma-rays from Pu isotopes	HRGS  ④: Ge-detector

Discussion between Panelists --1

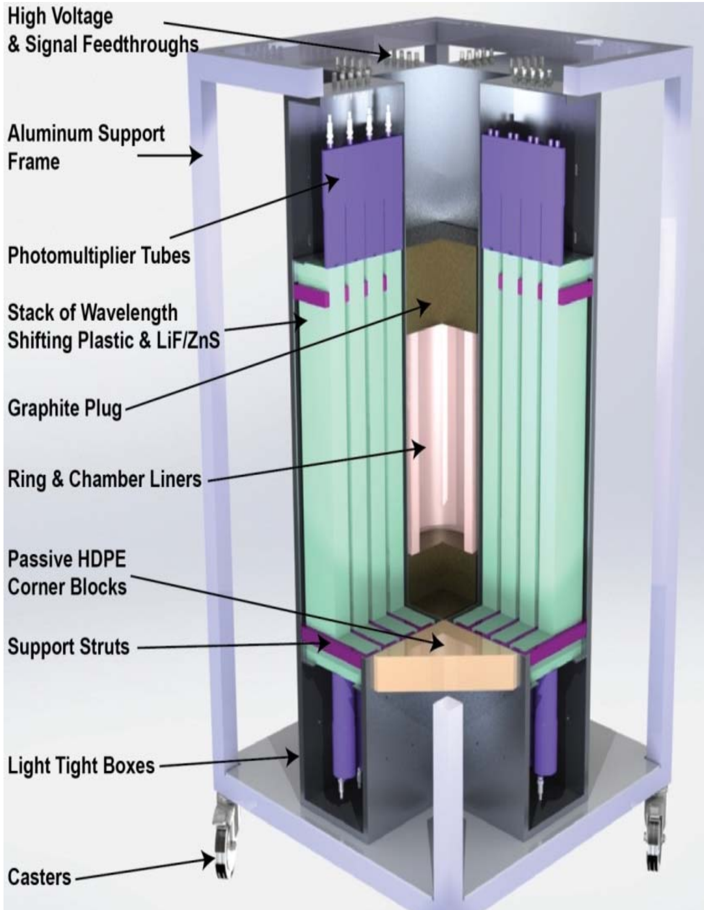
Alternatives to ^{3}He Detectors: Fast Neutron Detectors

- Advantages of detection of fast neutrons in coincidence counters
  - Less scattering-better penetration
  - Less effect of shielding
  - Lower signal/noise
  - Directionality
  - Imaging
  - Gamma rejection
  - Detect low Z material

Arden Dougan

LiF/ZnS Multiplicity Counter

- Rapid Pu inventory verification for MC&A
- Similar Figure of Merit to Epithermal Neutron Multiplicity Counter
- Anticipated Final Capabilities
  - Simulated counting efficiency: 52%
  - Simulated die-away time: 15 µsec
  - Sample acquisition time: 1000-3600 seconds
  - Pu mass assay precision goal: 1%
  - Weight: 1000 lbs
  - Footprint: 31” × 32” × 82”
  - Power: < 1 kW



Elements of Full Scale LiF/ZnS Neutron Multiplicity Counter

Pacific Northwest NATIONAL LABORATORY

Peter Schillebeeckx

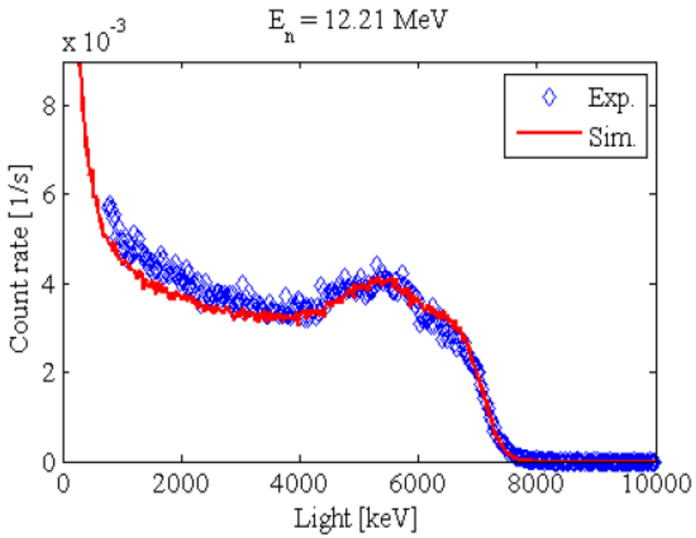
Verification of fuel assemblies

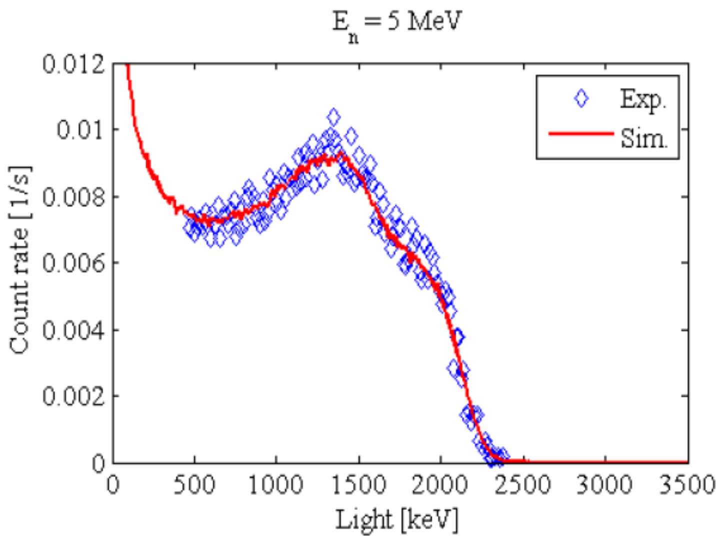
Conventional ^{3}He based system

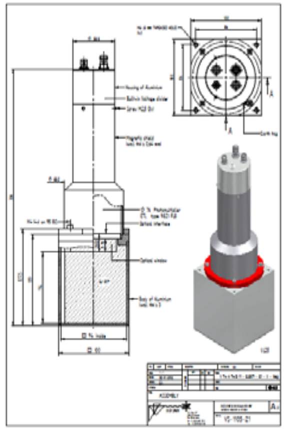
System based on
a EJ309 scintillator

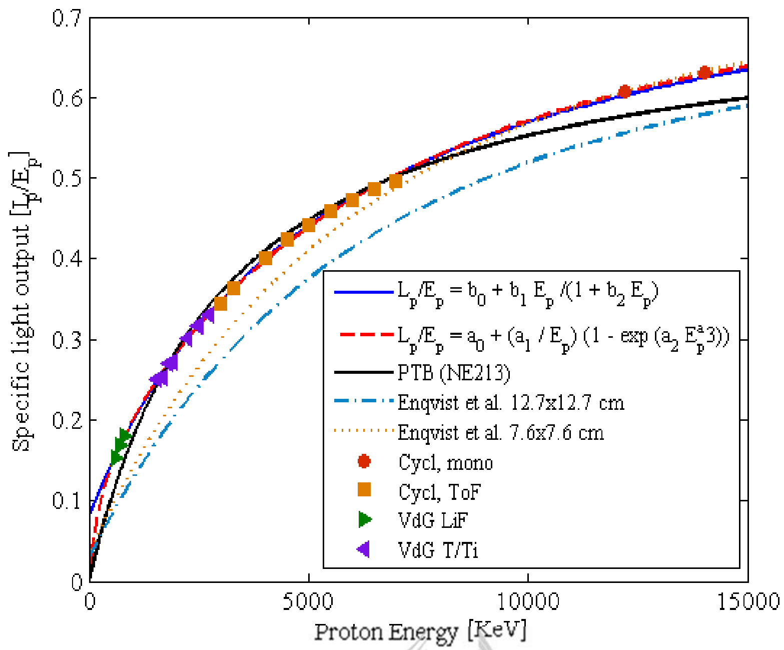
Peter Schillebeeckx

Characterization of a EJ309 scintillator at VdG



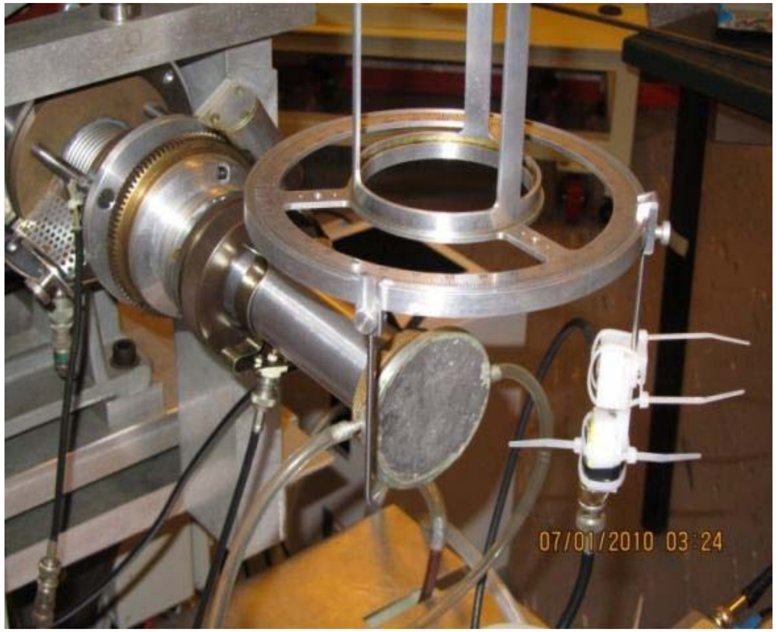


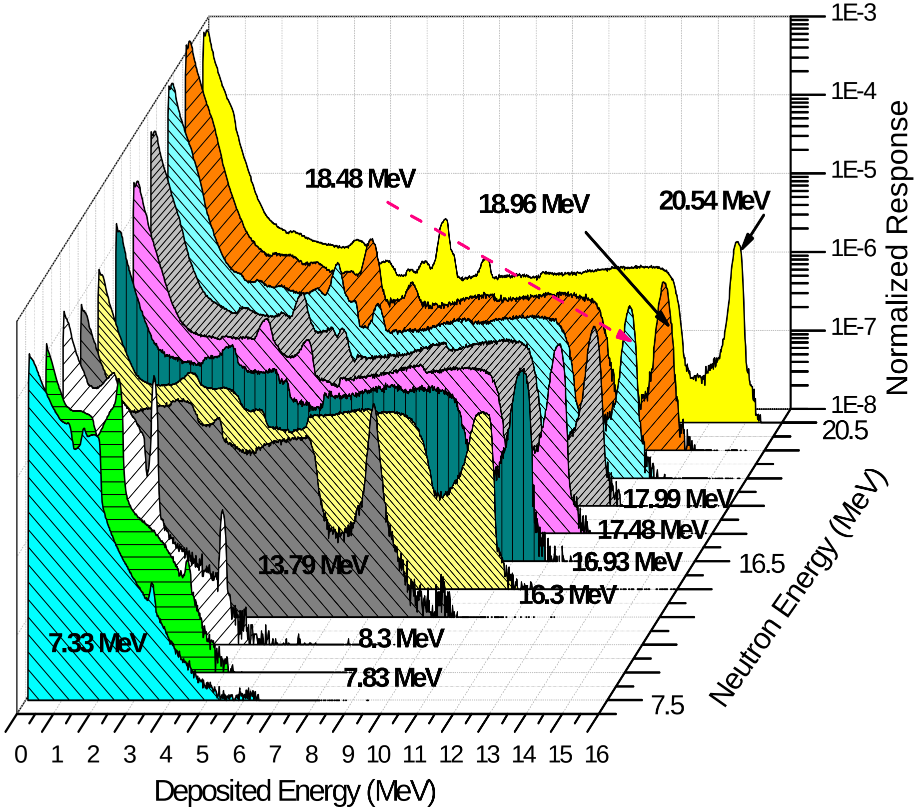




Peter Schillebeeckx

Characterization of other detectors : e.g. diamond





Peter Schillebeeckx

R&D NDA : detectors

- **Replacement ^{3}He**

- **Medium resolution γ-ray detectors**
  - **CdZnTl & LaBr: improved procedures for spectrum analysis**

Hirofumi Tomikawa

Evaluation Results of ASAS

ASAS: Alternative Sample Assay System
(using ZnS/B_2O_3 ceramic scintillator detectors as alternative to He-3 tubes)

	ASAS		INVS	
Counting Efficiency (e)	15.97%		30.82%	
Die-away Time (t in μs)	77.67		45.36	
Number of Tubes	24 ZnS/B_2O_3 Ceramic Scintillator Tubes		16 ^{3}He tubes	
Figure of Merit (FOM) <e^2/t>	**328.4**		**2094.1**	
Figure of Merit (FOM) <$e/t^{1/2}$>	**1.81**		**4.58**	
Total Measurement Uncertainty (Using MOX samples)	Passive Cal.	Known-α	Passive Cal.	Known-α
	3.91%	4.14%	3.66%	5.74%

ASAS
(Comparison with INVS)
-Counting Efficiency is smaller
-Die-away Time is longer
-FOM is smaller

→ ASAS can be used in actual safeguards inspection.

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Discussion between Panelists --2

February 10, 2016

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for Nuclear Nonproliferation and Nuclear Security

Mobile and Intense Neutron Source

Mitsuru Uesaka
Nuclear Professional School,
School of Engineering, University of Tokyo

Importance of Combination of X-ray- and Neutron Sources

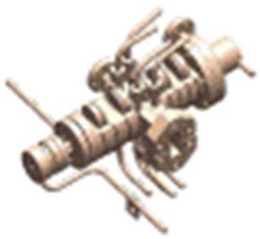
Law Concerning Prevention of Radiation Hazards Due to Radioisotopes

Deregulation??

Mitsuru Uesaka

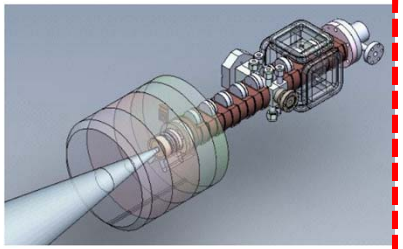
Portable X-band Linac X-ray Sources

Nuclear Medicine

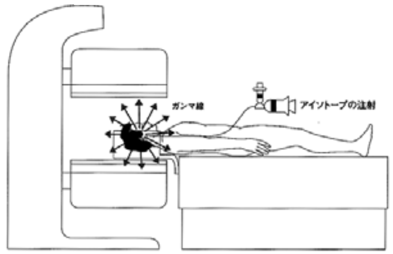


950 keV X-Band Linac

3.95 MeV X-Band Linac



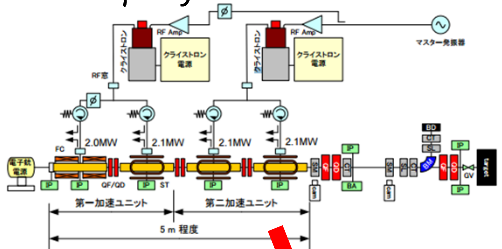
6 MeV X-Band Linac



Social Infrastructure

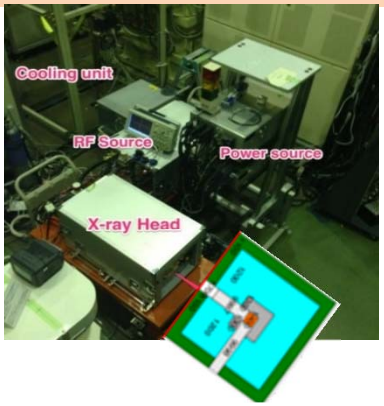
30 MeV X-Band Linac
γ-ray/neutron source

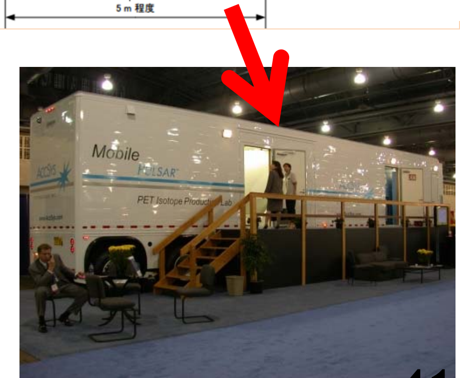
～1cm^t Metal Tube ～3cm^t ～40cm^t Fe-reinf. Concrete1-2m^t



Compact Neutron Sources

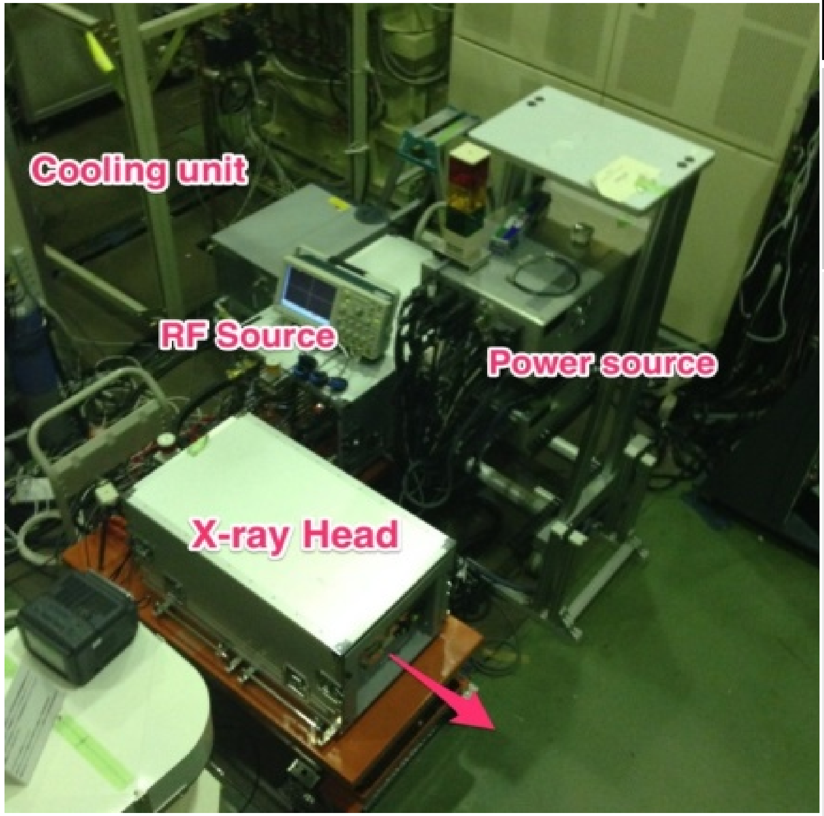
C_f Neutron Water Detector





Mitsuru Uesaka

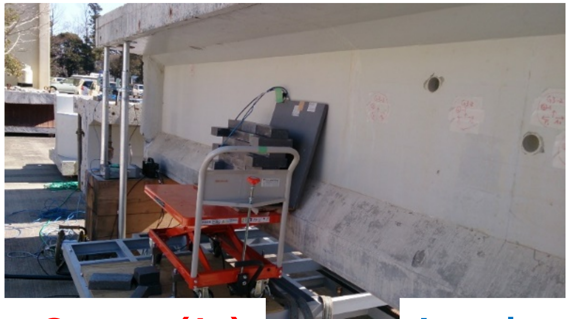
Mobile 3.95MeV X-band linac X-ray source of University of Tokyo



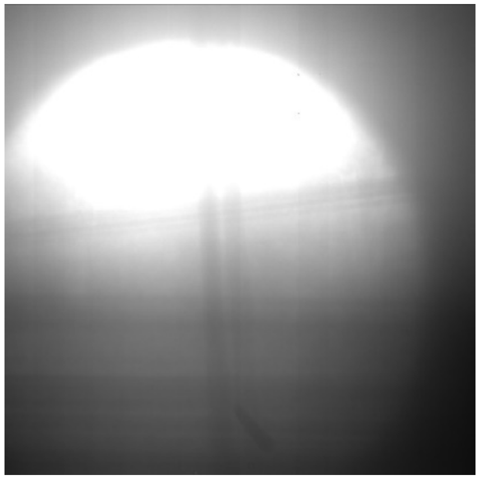
Main unit	Accelerating tube	RF Source	HVPS Control
Weight (kg)	80+62 (Collimator + Accelerating tube)	62	116
Parameters	Electron gun output current 300mA	Frequency 9.3GHz	
	Electron gun voltage 20kV	Pulse width 4μs	
	Beam current 100mA	Repetition rate 200pps	
		RF power output 1.5 MW	

Mitsuru Uesaka

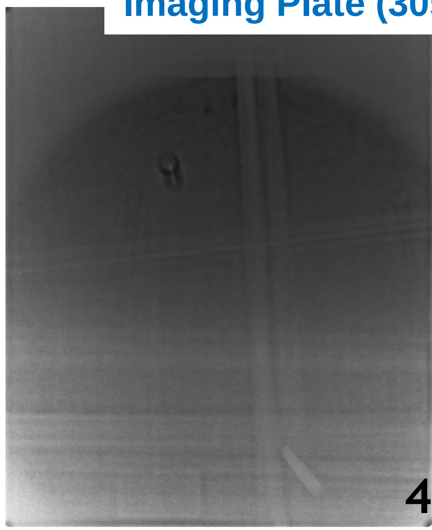
First Legal On-site Inspection of 3.95 MeV X-band Linac X-ray Source at Public Works Research Institute in Japan on January 29, 2015



X-ray Flat Camera(1s)



Imaging Plate (30s)



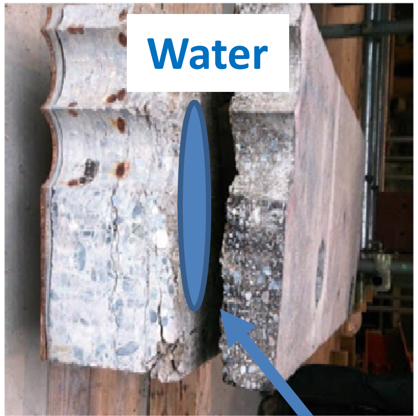
Mitsuru Uesaka

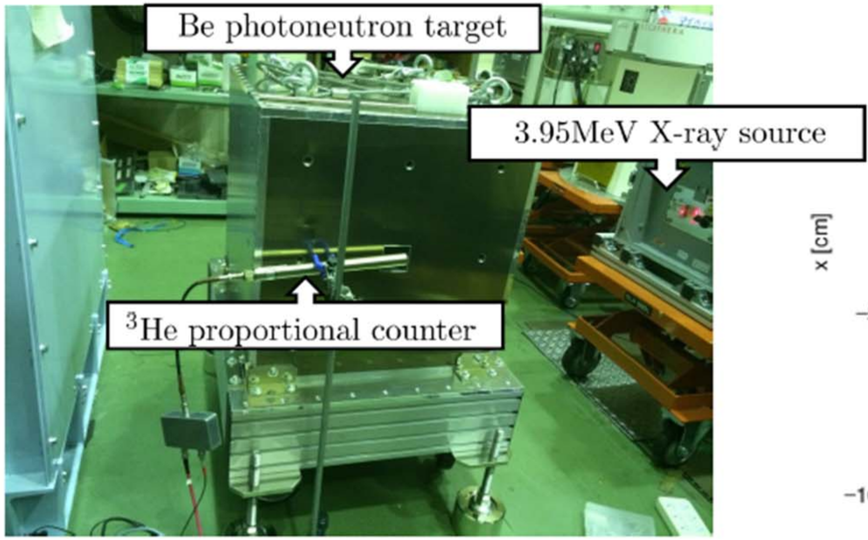
Safety Control for Bridge Inspection

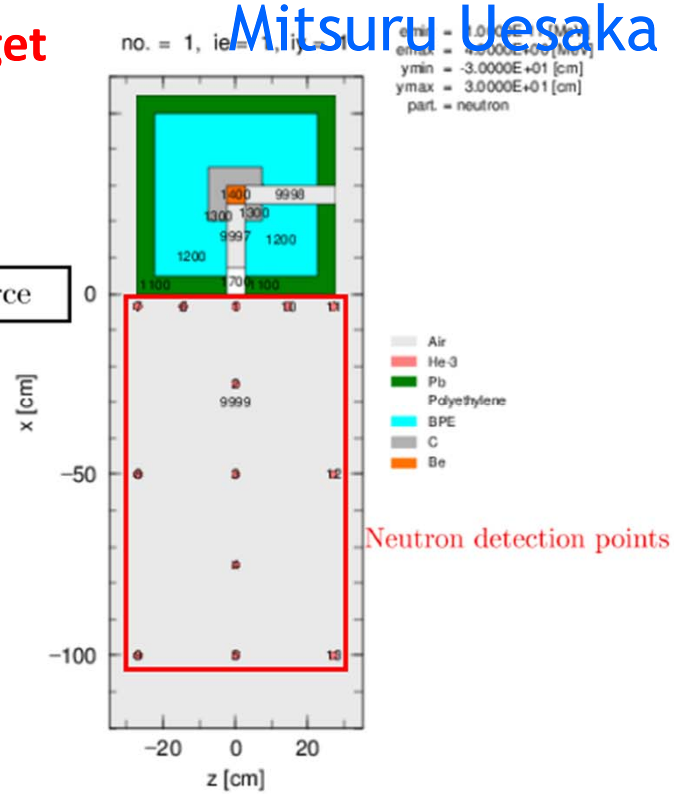
- Amendment of The Law Concerning Prevention of Radiation Hazards Due to Radioisotopes that allows use of below 4 MeV accelerator for only on-site bridge inspection was done in Japan in 2005.
- We registered 3.95 MeV electron linac X-ray source as a radiation source to Nuclear Regulation Authority (NRA) in 2014.
- Then, we design and set a radiation controlled area over 1.3 mSv/3 months and a facility boundary of 250 μSv/3 months under Regulations on Prevention of Ionizing Radiation Hazards and submit the application of on-site use to Nuclear Regulation Authority (NRA).
- Finally, we can perform the on-site bridge inspection.

Mitsuru Uesaka

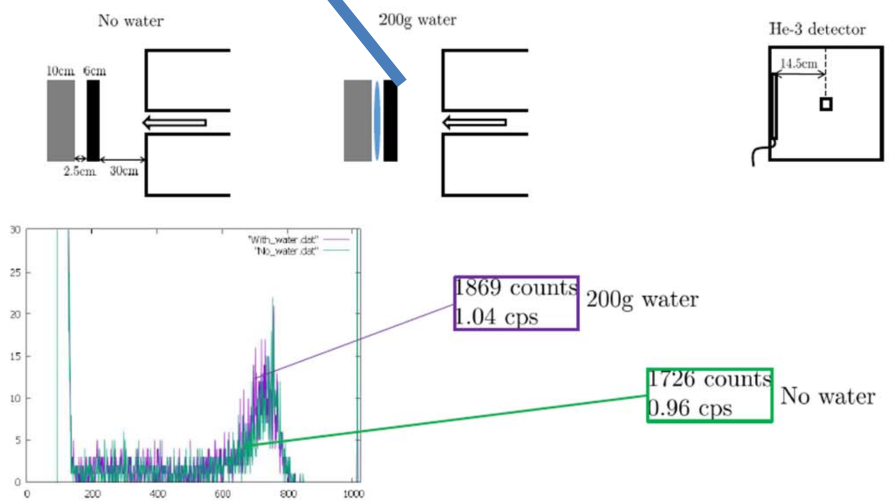
3.95 MeV X-band Electron Linac X-ray Source + Be Target ➡ Mobile and Intense Neutron Source







Neutron moisture detection



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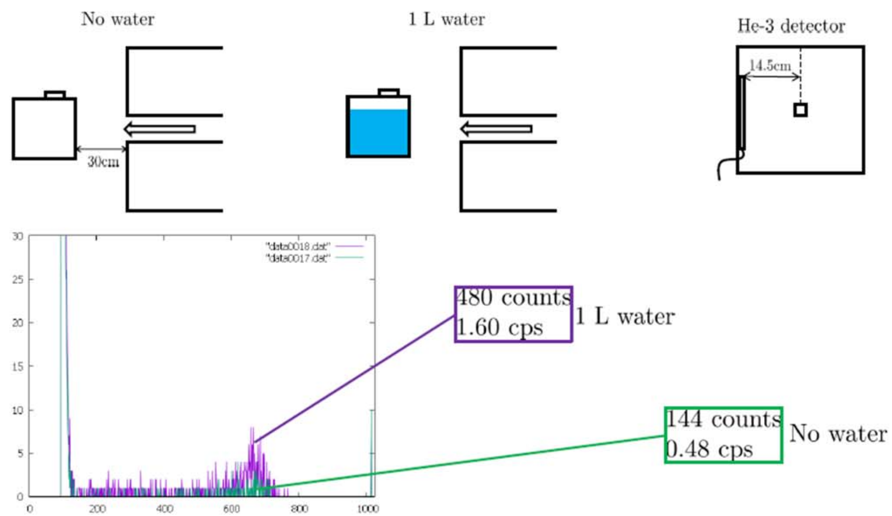


Mitsuru Uesaka

Intensity and Application of Compact Accelerator Neutron Sources

To be published in Ch. of “Compact Neutron Source” in “Accelerators for Science and Technology ” in Reviews of Accelerator Science and Technology (World Scientific)

10^{9} — 10^{10} — 10^{11} — 10^{12} — 10^{13} — 10^{14} — 10^{15} — 10^{16} — 10^{17} neutrons/sec

RI Neutron Source (^{252}Cf 2MBq (0.1 μg) = 2.3 × 10^{5} n/s)

100 keV D Acceleration and Shielded T Target

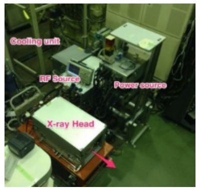
Electron linac based

S-band 40MeV 1kW Electron Linac

L-band 30MeV 6kW Electron Linac

Short pulse for thermal~epi.~keV Neutrons and Nuclear data

X-band 3.95 MeV 0.4kW Electron Linac



RI Production for Nuclear Medicine

BNCT

7MeV Proton Linac

Non-Destructive Testing

8 MeV Proton Linac

2.5 MeV Proton Linac

30MeV Proton Cyclotron

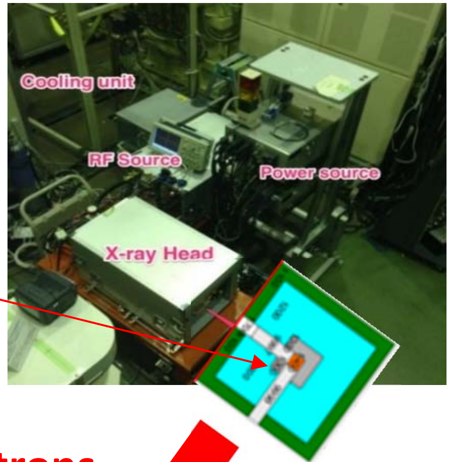
30MeV D+ Cyclotron + C Target

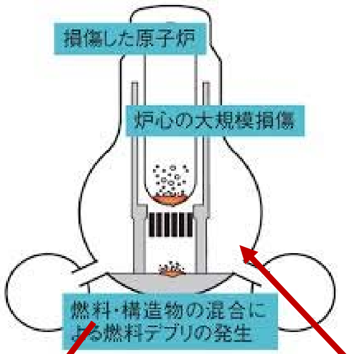
P^{+} or D^{+} accelerator based

Mitsuru Uesaka

On-site Neutron Inspection by X-band 3.95 MeV Electron Linac Neutron Source

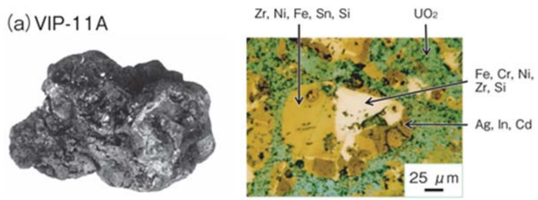
10^{11} n/sec





Neutrons

Security Inspection



Nuclear Material Evaluation
in Melted Fuel Debris
in Fukushima TEPCO Daiichi NPP site

Mitsuru Uesaka

Safety Control for Neutron Use

- Below-4 MeV accelerators can be used for only on-site bridge inspection in a radiation controlled area over 1.3 mSv/3 months and a facility boundary over 250 μSv/3 months under Regulations on Prevention of Ionizing Radiation Hazards in Japan.
- Neutrons should be also monitored, added to the above doses and controlled.
- We are continuously consider the deregulation of other on-site uses except the bridge inspection.

Innovation for Current Safeguards: Software

- Improved correlated neutron counting
  - More accurate and complete information from neutron data
  - Based on fundamental physics
  - Improve multiplicity analysis by utilizing high order moments (quads and pents)
  - Dead time correction
  - Validation

Arden Dougan

Improvements to Current Safeguards: Counting Standards

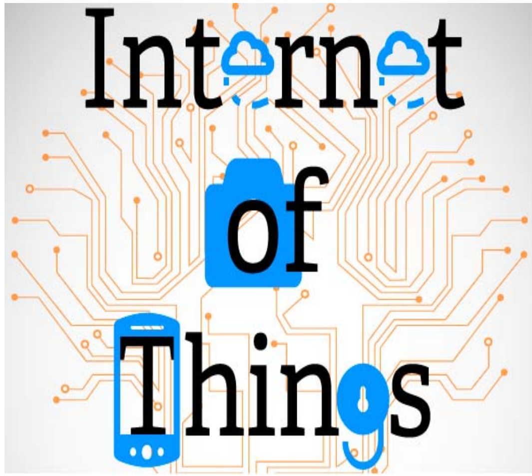
- ^{233}U
  - Sets of small counting standards of ^{233}U will be fabricated and distributed across the DOE complex to help maintain the infrastructure, experience, and expertise in evaluating ^{233}U signatures.
- ^{244}Pu
  - ^{244}Pu that originated from Mark-18 targets that were previously stored at ORNL, was shipped to Russia in 2005 for enrichment in VNIIEF's calutrons
    - The enriched product material (99.985 %) was returned to the United States in May 2015.
  - This material will be fabricated into CRMs by 2018.
    - 60% of the CRMs produced will be provided to the IAEA and 40% will be retained in the United States.

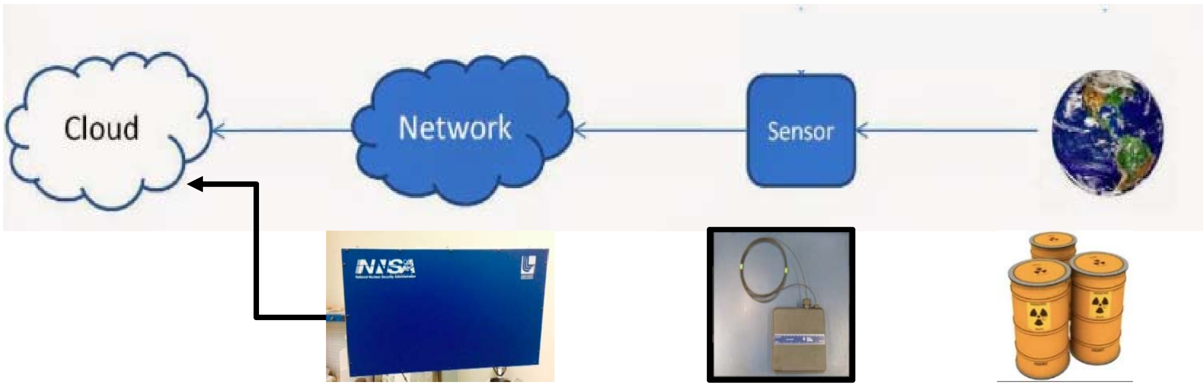
Sealed, (2.5 cm diameter × 1jcm height), low-activity (~10 µCi), high-purity (>99.9%) ^{233}U gamma-ray sources

Arden Dougan

Internet of Things (IOT): The Next Technological Revolution

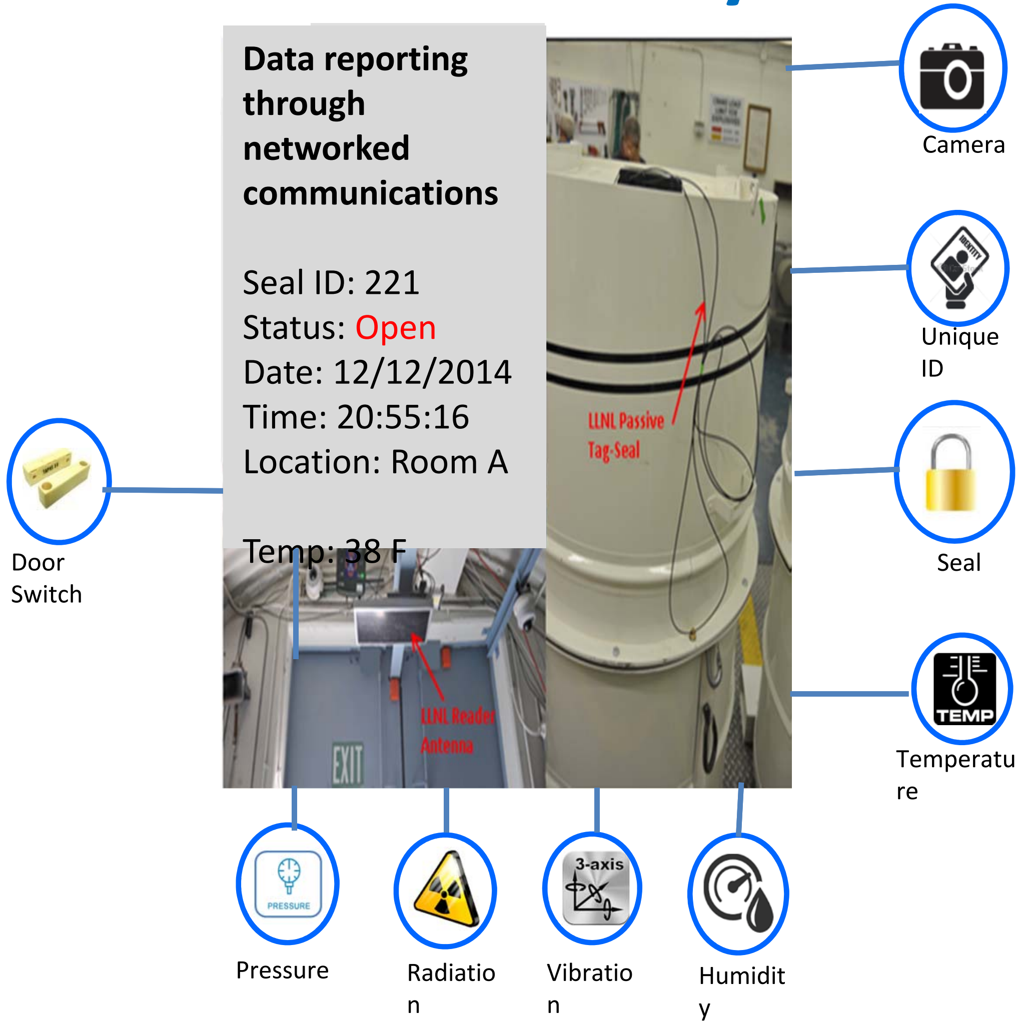
- IOT is a network of sensors connected to server/cloud for reporting events for processing and sharing
  - Reliable connectivity
  - Sensing a complex environment
  - Low cost
  - Low power
  - Security
  - Persistent and active self-monitoring
  - Integration across devices





Arden Dougan

DOE’s Vision for IOT in Safeguards Has Existed for Many Years



Hirofumi Tomikawa

Advanced Pu direct monitoring technical development

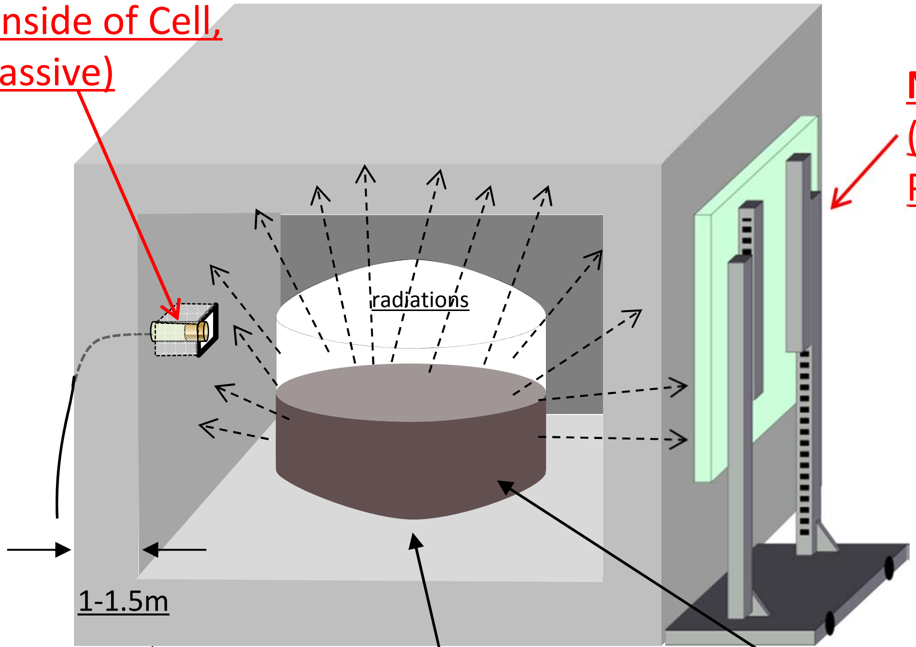
Development of a new technology for continuous measurement and monitoring Pu with FP

Expected Effects and Results

- This technology can be applied to real time monitoring for entire reprocessing process.
- Continuous monitoring technology can be extended to detect security events.

Image of Pu monitoring technology development

NEW Detector (Inside of Cell, Passive)



NEW Detector (Out of Cell, Passive)

Concrete Cell

Pu solution including FP

High Active Liquid Waste tank

Design and Composition Survey
- Pu concentration
- density
- Pu isotopic composition
- impurity contents and nuclides etc.

Radiation Study
Various radiation measurements

Simulation
evaluation of candidate technologies

Measurement test
Fabrication of prototype detector and evaluation of function

Items of Panel Discussion 1 ”Challenges of Technology Development for Future Safeguards”

i	Support of R&D for NDA in Verification Technologies (1/2)	
	1	Development of Neutron Counting Systems using Alternative Detectors to ^{3}He
	2	Innovative R&Ds for Improvement of Present SG Equipment
	3	NDA Techniques / Systems for LWR Spent Fuel Assemblies
ii	Safeguards by Design “SBD” for (Large Size) Automated Nuclear Facilities	
	4	Safeguards by Design “SBD” for Nuclear Facilities
iii	Support of R&D for NDA in Verification Technologies (2/2)	
	5	Development of NDA Technologies for Pu, Am, Np, Cm in Mixtures

Background Needs

Increment of quantities of LWR spent fuel assemblies

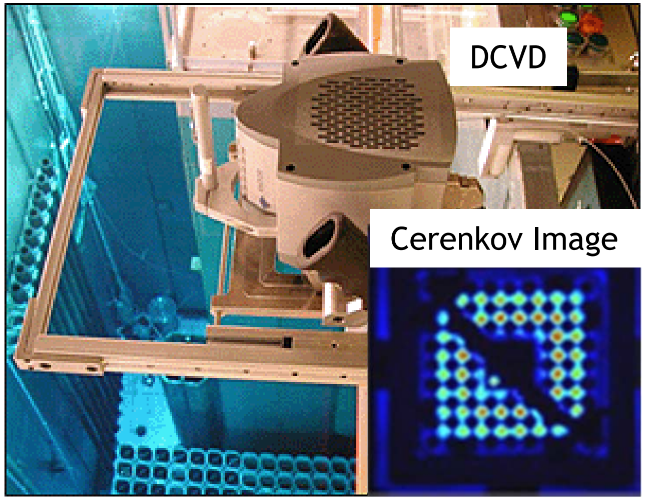
▪	Increment of number of LWRs in the world [Re-startup of LWRs in Japan]
▪	Intermediate Storage of Spent Fuel Assemblies of LWRs
▪	Geological Disposal of Spent Fuel Assemblies of LWRs

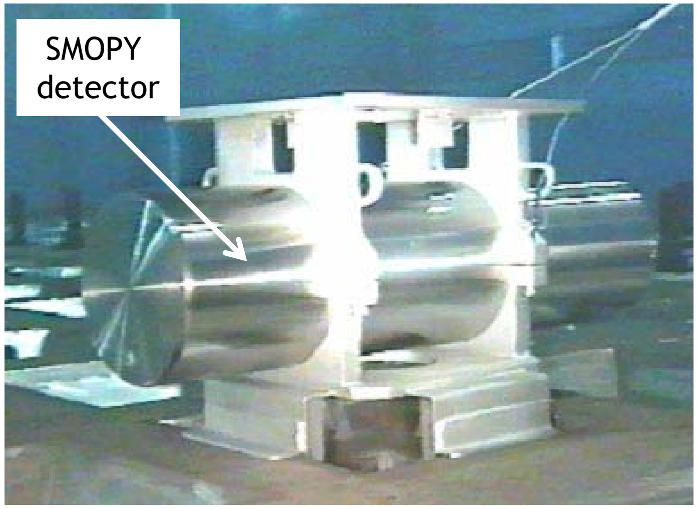
(SFA: spent fuel assembly/assemblies)

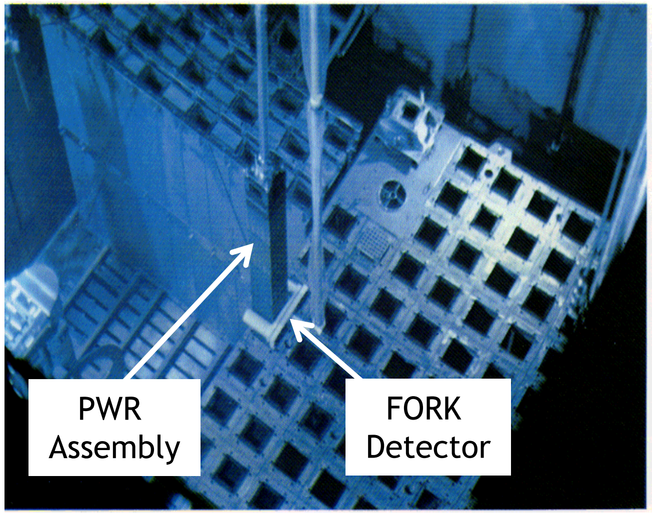
Challenges:
Quantitative NDA Technologies of NM (Pu etc.) in SFA

Present NDA Devices for LWR-SFA

– Cerenkov Viewing Device（ICVD, DCVD）
  - -Detects Cerenkov glow from water around assembly
– FORK and SMOPY
  - -Fission chambers → total neutron（driven by ^{244}Cm）
  - -Ion chambers and CdTe → FP gamma-rays
– Spent Fuel Attribute Tester（SFAT）
  - - ^{137}Cs is present







→ Present NDA devices for SFA check only attributes of SFA.

Present Situation of NDA for Quantification

NDA Systems for Quantification of NM	
Fresh MOX Fuel	-Various passive type NDA systems with neutron coincidence counting using ^{3}He detectors have been used. -NDA accuracies of ^{240}Pu-effective are less than several %.
Spent Fuel Assemblies (SFA)	-No NDA systems for quantification of NM in SFA have been developed. → NGSI (USDOE) program

Minor Actinides co-existing with Pu in SFA

Half-life, Neutron Yields, Decay Heat of U/Pu/Minor Actinides(Np/Am/Cm) Isotopes

Nuclides (Isotopes)	Half-life (y)	Neutron Yield (n/s-g)	Decay Heat (W/kg)	Remarks
^{235}U	7.0×10^{8}	2.99×10^{-4}	6×10^{-5}	Fissile
^{238}U	4.5×10^{9}	1.36×10^{-2}	8×10^{-6}	
^{237}Np	2.1×10^{6}	1.14×10^{-4}	2.1×10^{-2}	
^{238}Pu	8.8×10^{1}	2.59×10^{3}	5.7×10^{2}	Spontaneous Fission
^{239}Pu	2.4×10^{4}	2.18×10^{-2}	2.0	Fissile
^{240}Pu	6.54×10^{3}	1.02×10^{3}	7.0	Spontaneous Fission
^{241}Pu	1.47×10^{1}	4.93×10^{-2}	6.4	Fissile
^{242}Pu	3.76×10^{5}	1.72×10^{3}	1.2×10^{-1}	Spontaneous Fission
^{241}Am	4.33×10^{2}	1.18	1.15×10^{2}	
^{244}Cm	1.81×10^{1}	1.08×10^{7}	2.8×10^{-3}	Spontaneous Fission

Difficulties of NDA for Quantification of NM in SFA

Fresh MOX Fuel Assembly	Spent Fuel Assembly (SFA)
U, Pu MA(Am)	U, Pu, MA(Np, Am, Cm),FP
Not so high radiation	**Very high radiation** Gamma-ray : Mainly from FPs Neutron : Mainly from Cm-244

Factors leading to difficulty of NDA of Pu in SFA
-Existence of MA (Cm-244) : Very high neutron yield of Cm-244 makes it difficult to apply neutron coincident counting
-Existence of very strong gamma-rays : Very high strong gamma-rays makes self-emission gamma-rays from Pu isotopes be buried in the BG

Discussion between Panelists --3

Arden Dougan

New Technologies for Spent Fuel NDA


PDET

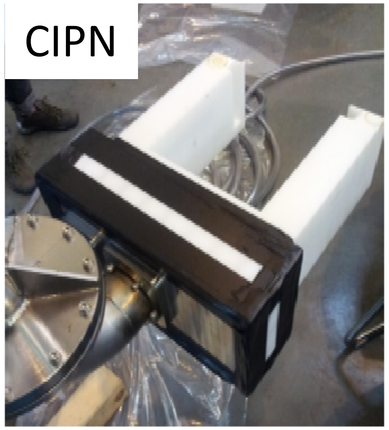

DDSI

Passive:

- **Time correlated neutrons** [Differential Die-away Self-Interrogation (DDSI)]
- **Comparison of high and low multiplying sections** [Passive Neutron Albedo Reactivity (PNAR)]
- **Guide tube neutron and gamma detection** [Partial Defect Verification of Spent Fuel (PDET)]
- **High count test platforms** [HPGe and $LaBr_3$ for gammas; B-10 for neutrons]

Active:

- **Time-varying neutron interrogation** [Differential Die-away (DDA)] – not shown
- **Continuous neutron interrogation** [Californium Interrogation with Prompt Neutron (CIPN)]
- **Active neutron coincidence counting** [Advanced Experimental Fuel Counter (AEFC)]


CIPN


AEFC

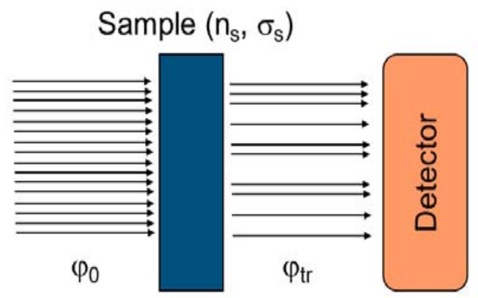

HPGe

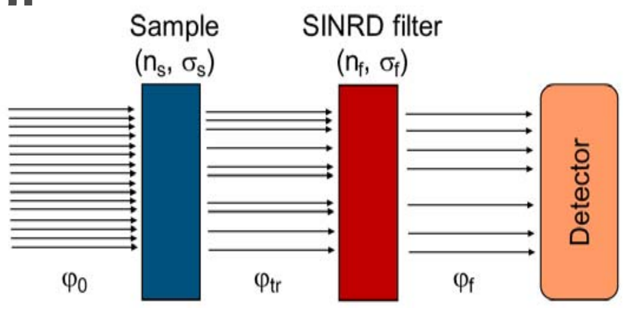

PNAR

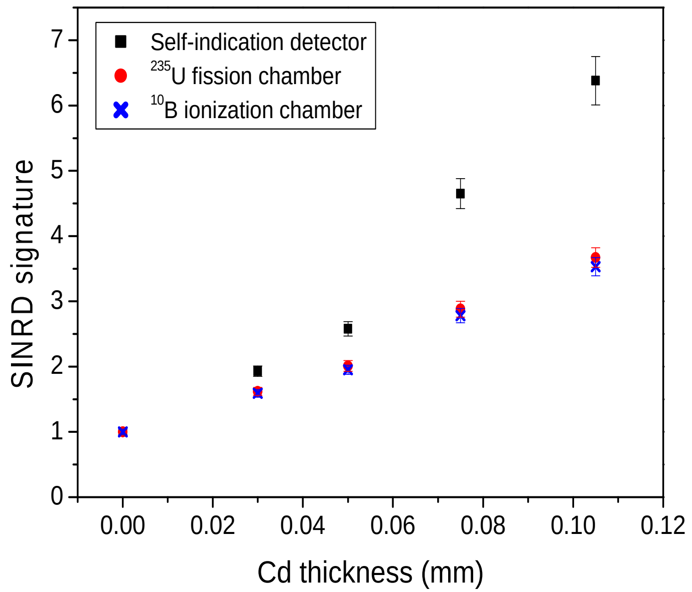
Peter Schillebeeckx

Self-Indication Neutron Resonance Densitometry

- **First proposed at LANL**
- **R&D : collaboration SCK•CEN and JRC Geel SINRD for spent fuel assemblies in dry storage area**
  - Experimental validation of the concept
  - Development of detectors







Peter Schillebeeckx

R&D NDA : detectors

- **Small neutron detectors for spent fuel measurements with specific sensitivity to e.g. ^{235}U & ^{239}Pu**
  - **For SINRD**

Items of Panel Discussion 1 ”Challenges of Technology Development for Future Safeguards”

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Necessity of SBD for Effective SG Verification of NM in Process

In (large size) automated nuclear facilities treating NM with very high radiation, people (operators/inspectors) can not go inside the process area. For this kind of facility, it is necessary to integrate SG verification systems into facility operation systems.

-Reprocessing Plants, MOX Plants
-New Types of Nuclear Facilities (treating NM with very high radiation)
***Next Generation Aqueous-base Reprocessing Facilities**
***Pyro processing facilities**
***Transmutation fuel (ADS fuel) facilities**

Discussion between Panelists --4

Essence of SBD (1/2)

Michio Seya

Integration of SG NDA Systems into Facility Operation Systems

(An Example of JAEA/PFPF Case)

SG System

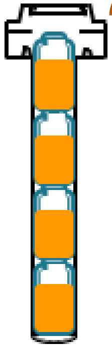
NDA System
HLNCC (NCC type)

Specially Designed
Canister NDA System
(NCC type)

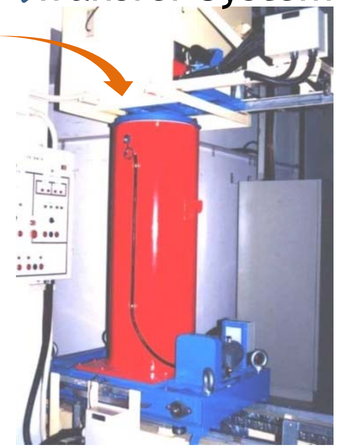
Integration of NDA System
into Transfer System

Facility Operation System

NM
Canister

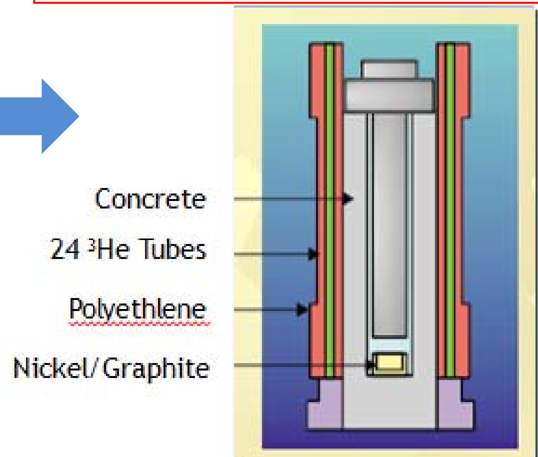


NM Canister
Transfer System



Advantages of SBD
Inspection Side Could obtain NDA data at every transfer of the canister in Head Office of IAEA (Reduction of Person Days of Inspection)
Operation Side No necessity of stopping operation (Reduction of interference by Inspection)

PCAS is able to measure NM in the canister during transfer in unattended mode.



PCAS
(IAEA use)

(PCAS: Plutonium Canister Assay System)

Essence of SBD (2/2)

Michio Seya

Integration of SG NDA Systems into Facility Operation Systems

SBD (integration of SG (NDA) system into facility operation system) gives advantages to both of inspection and operation sides with

-Inspection Side: Reduction of Person Days of Inspection

-Operation Side: Reduction of interference by Inspection.

For integration of SG (NDA) systems into facility operation systems

-NDA technology (NCC in this case) has to be well developed before the design of the nuclear facilities.

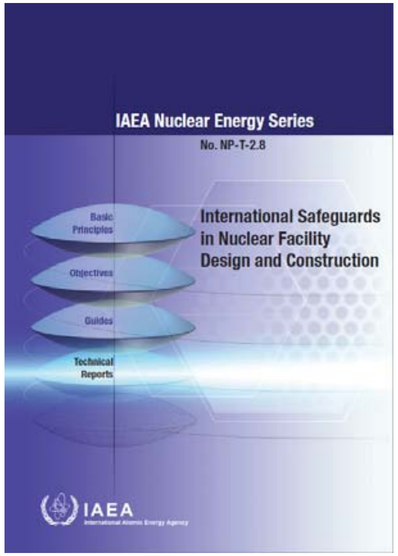
→Facility operators (or member states etc.) **need to start early development of adequate SG systems well before** the design the new types of facility

Hirofumi Tomikawa

IAEA SBD guidance documents

- **IAEA has developed SBD guidance for designers and operators via member state support program.**
- **The guidance documents are published.**

  - **Basic guidance for management**:
    - ✓ International Safeguards in Nuclear Facility Design and Construction (Published in 2013)
  - **Facility-specific guidance for designers**:
    - ✓ Nuclear Reactors (Published in 2014)
    - ✓ Conversion Plants
    - ✓ Fuel Fabrication Plants
    - ✓ Spent Fuel Management
    - ✓ Enrichment Plants
    - ✓ Reprocessing Plants



JAEA also support to develop the guidance via Japan support program.

IISS

Safeguards by Design' is more difficult to employ in cases where new nuclear facilities were not reported to the IAEA at the initial stage.

- **Iran and India examples – for different reasons.**
- **North Koreas' facilities might be another future case.**

Managing the cost of safeguards is a policy consideration.

- **If India puts more facilities under safeguards, who will pay?**
- **If Rokkasho begins full-scale operations, safeguards costs will increase.**

Items of Panel Discussion 1
"Challenges of Technology Development for Future Safeguards"

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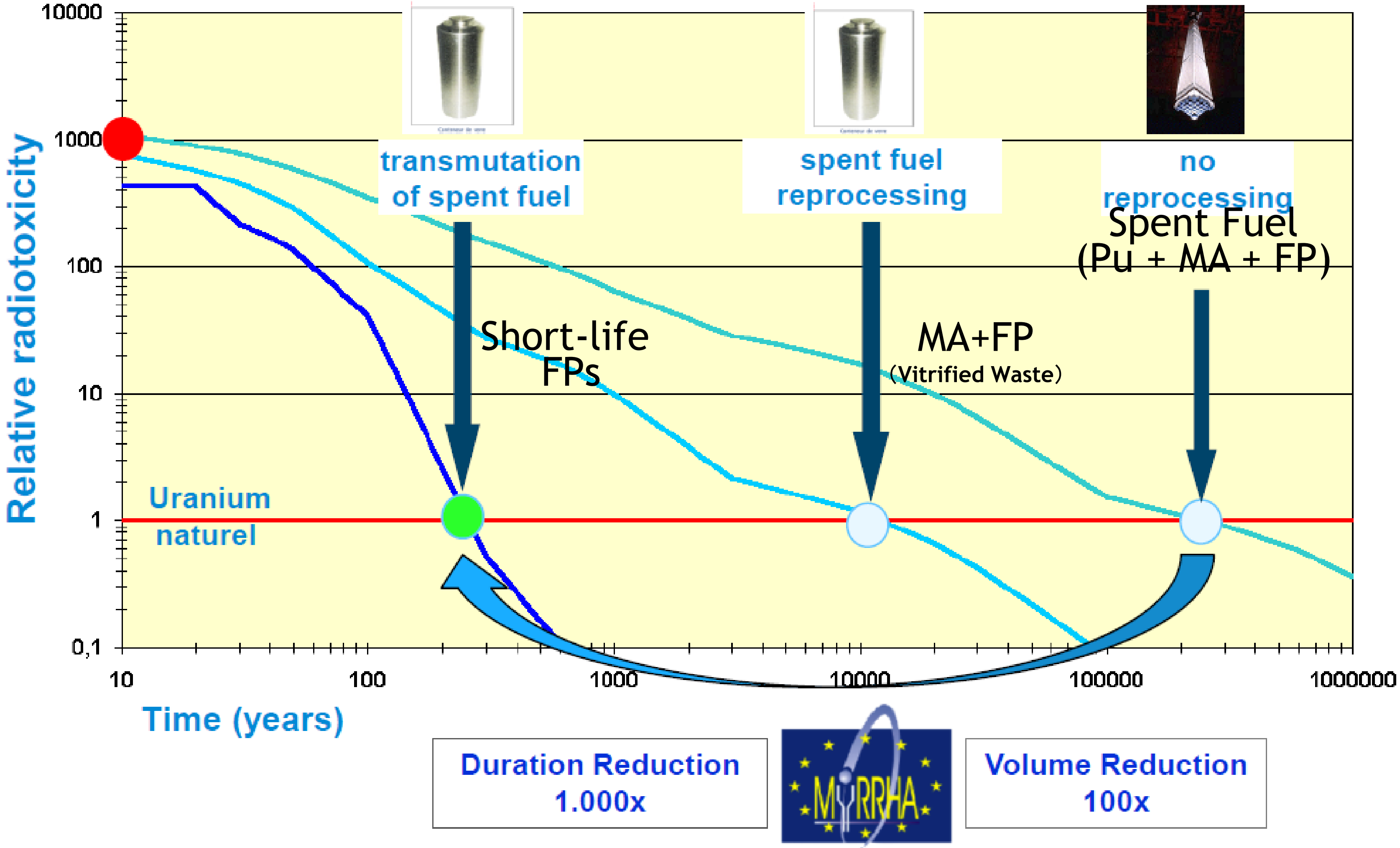
Transmutation of MA and Long-life FP

For Large Shortening of Control Duration
[several hundred thousand years ⇒ several hundred years]



Transmutation of MA and Long-life FP

①	**Transmutation of MA in Fast Reactor**
	PUREX-base TRU recovery process ＋ FR MOX Fuel production
②	**Transmutation of MA in the ADS**
	Separation of MA in Reprocessing and Pu + ADS Fuel (Nitrides / Oxides etc.) Fab. → Irradiation in ADS → Recovering MA, Pu → ADS Fuel (Nitrides / Oxides etc.) Fab.

Difficulties of NDA for Quantification of MA in Mixtures of Pu and MAs

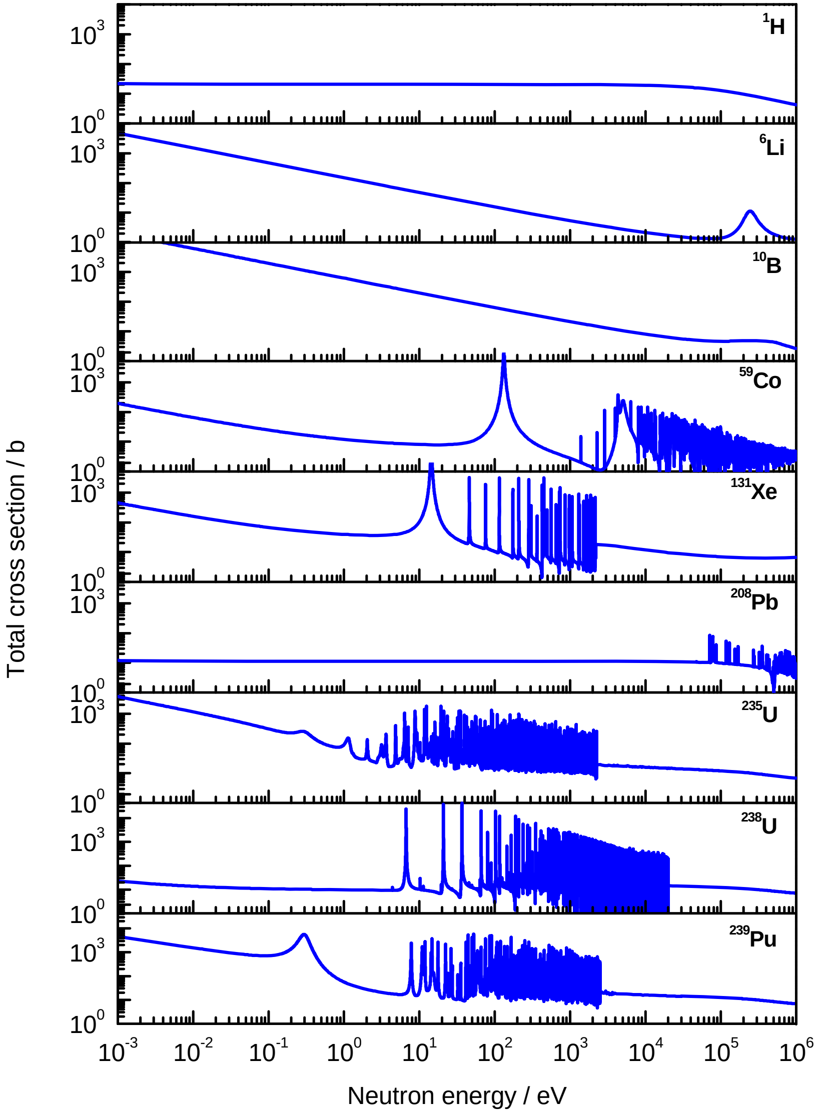
Fresh MOX Fuel Assembly	Spent Fuel Assembly (SFA)	ADS (Spent) Fuel Mixtures of Pu, MAs
U, Pu MA(Am)	U, Pu, MA(Np, Am, Cm), FP	Pu, MA(Np, Am, Cm), FP
Not so high radiation	Very high radiation Gamma-ray : Mainly from FPs Neutron : Mainly from Cm-244	Very high radiation Gamma-ray : Mainly from FPs Neutron : Mainly from Cm-244

→Necessity of Active Type NDA Technologies

Discussion between Panelists --5

Peter Schillebeeckx

Neutron Resonance Analysis (NRCA&NRTA)



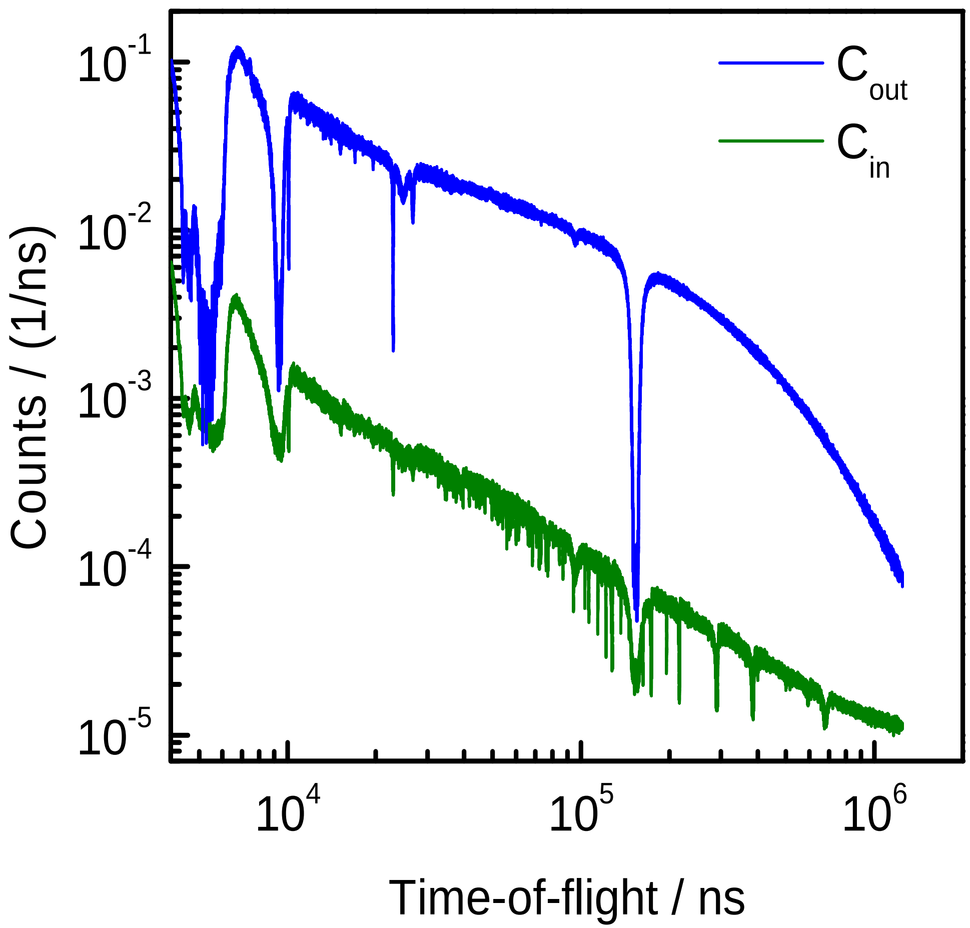
- Cross section is a measure for the interaction probability
- Resonances appear at energies, which are specific for each nuclide
- Position and amplitude of resonances can be used as fingerprints to
  - identify and quantify nuclides
  - elemental & isotopic composition
- NRTA & NRCA, developed at JRC-IRMM
  - Non-Destructive Analysis (NDA)
  - sensitive to almost all nuclides (except light)
  - no sample preparation required
  - requirements:
    TOF-measurements at a white neutron source

Peter Schillebeeckx

NRTA at GELINA : Nuclear Material

U_3O_8 reference sample
EC NRM 171

Strong impact
of matrix material



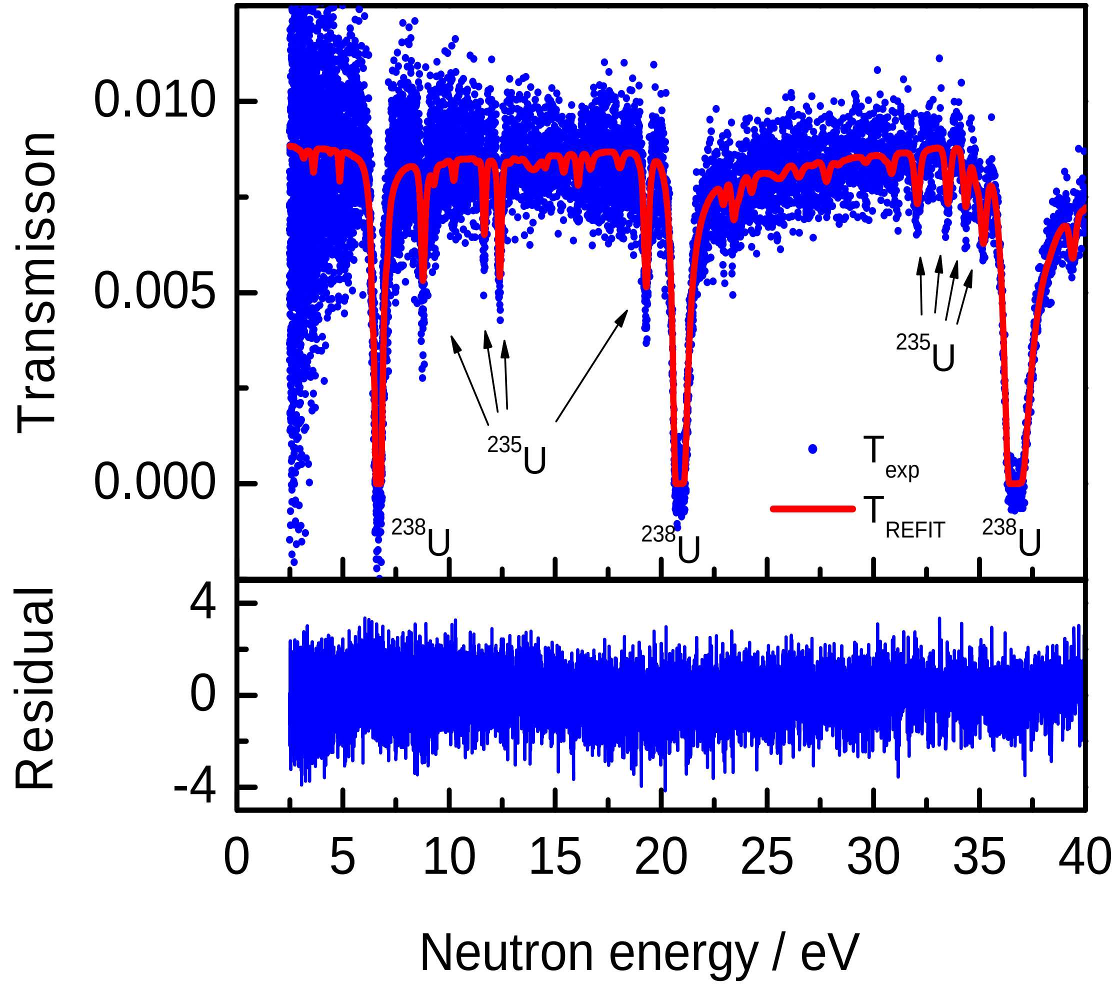
Peter Schillebeeckx

NRTA at GELINA : Nuclear Material

U_3O_8 reference sample
EC NRM 171

Beam attenuation
due to matrix
~ 99%

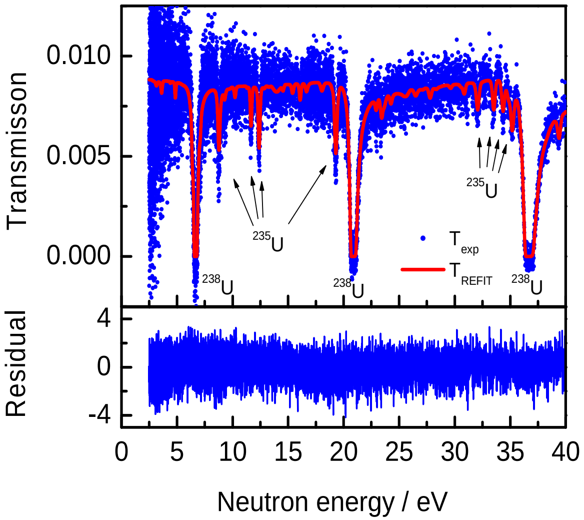
Fit for areal density



Peter Schillebeeckx

NRTA at GELINA : Nuclear Material

U-isotope	Areal number density (at/b)		Ratio
	Declaration	NRTA	
^{235}U	$(5.0326 \pm 0.0080) \times 10^{-4}$	$(5.063 \pm 0.09) \times 10^{-4}$	**1.006**
^{238}U	$(1.0628 \pm 0.0015) \times 10^{-2}$	$(1.062 \pm 0.01) \times 10^{-2}$	**0.999**



$\Rightarrow$ bias < 1.0 %

- Accurate & absolute NDA technique
- No calibration requirements using representative reference materials

$\Rightarrow$ Analytical technique

$\Rightarrow$ Applications:
  - Melted fuel (Fukushima)
  - Sampling at reprocessing facilities

Peter Schillebeeckx

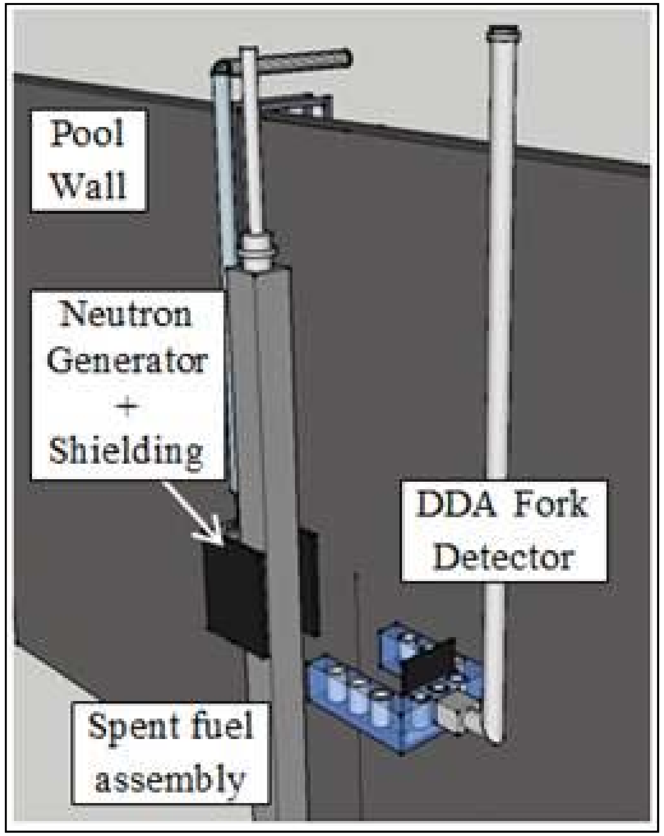
R&D NDA : nuclear data

- NRA
  - Improved resonance parameters for MA (Am, Cm, …) & FP
- Gamma-ray spectroscopy
  - Absolute isotopic measurements : decay data
- Modelling of neutron based systems
  - Prompt neutron multiplicity distributions

Arden Dougan

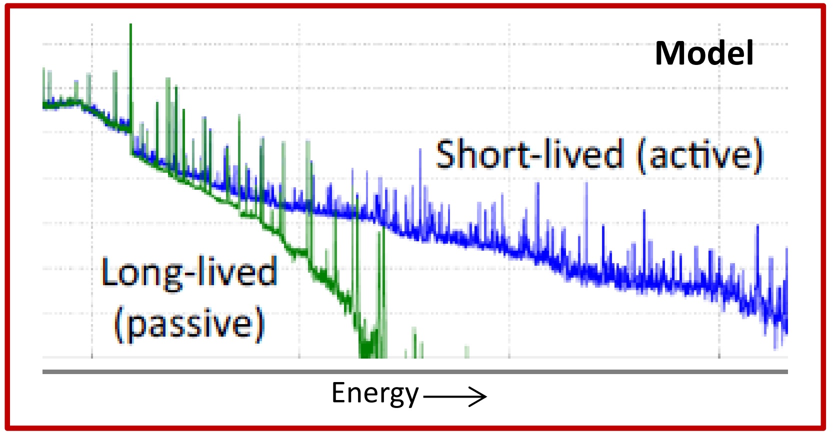
Differential Die-away Assay (DDA) Instrument

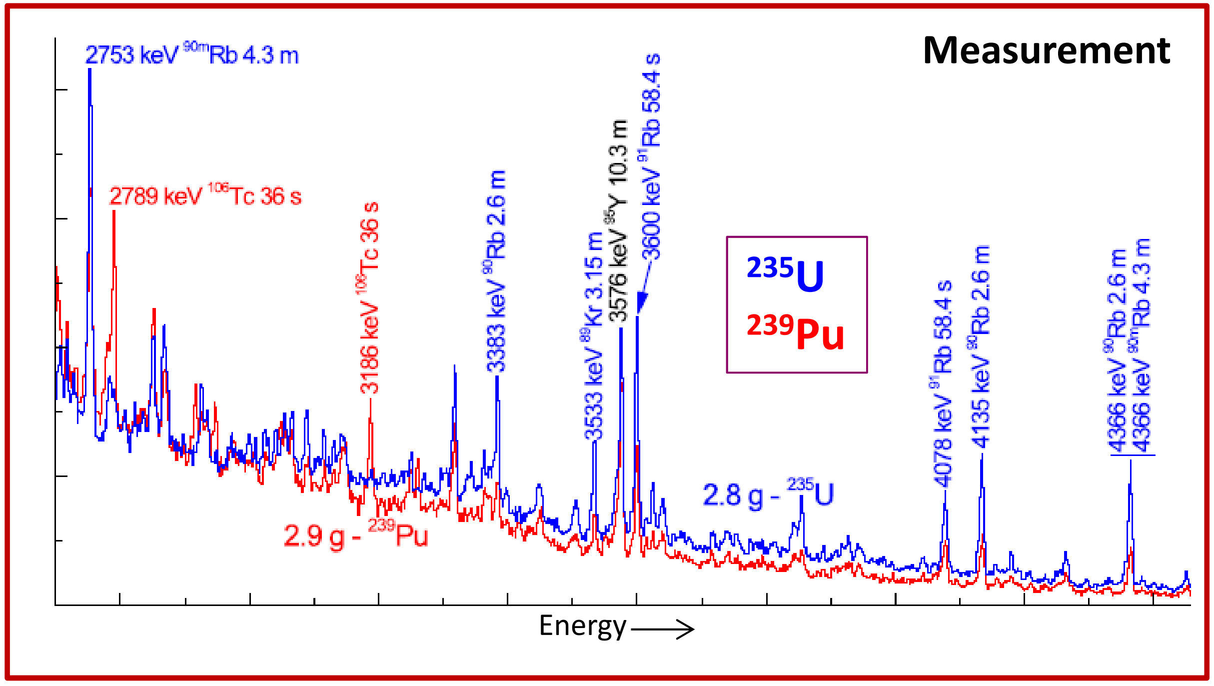
- Fast quantification of plutonium in spent fuel with less than 2% uncertainty
- Transportable and independent of facility design
- High sensitivity to small changes in the amount of fissile material in the fuel assembly
  - Removal/replacement of 10 pins can be detected



Delayed Gamma Spectroscopy

- Experiments at Idaho Accelerator Center show clear difference between ^{235}U and ^{239}Pu
- Good agreement between models and measurements

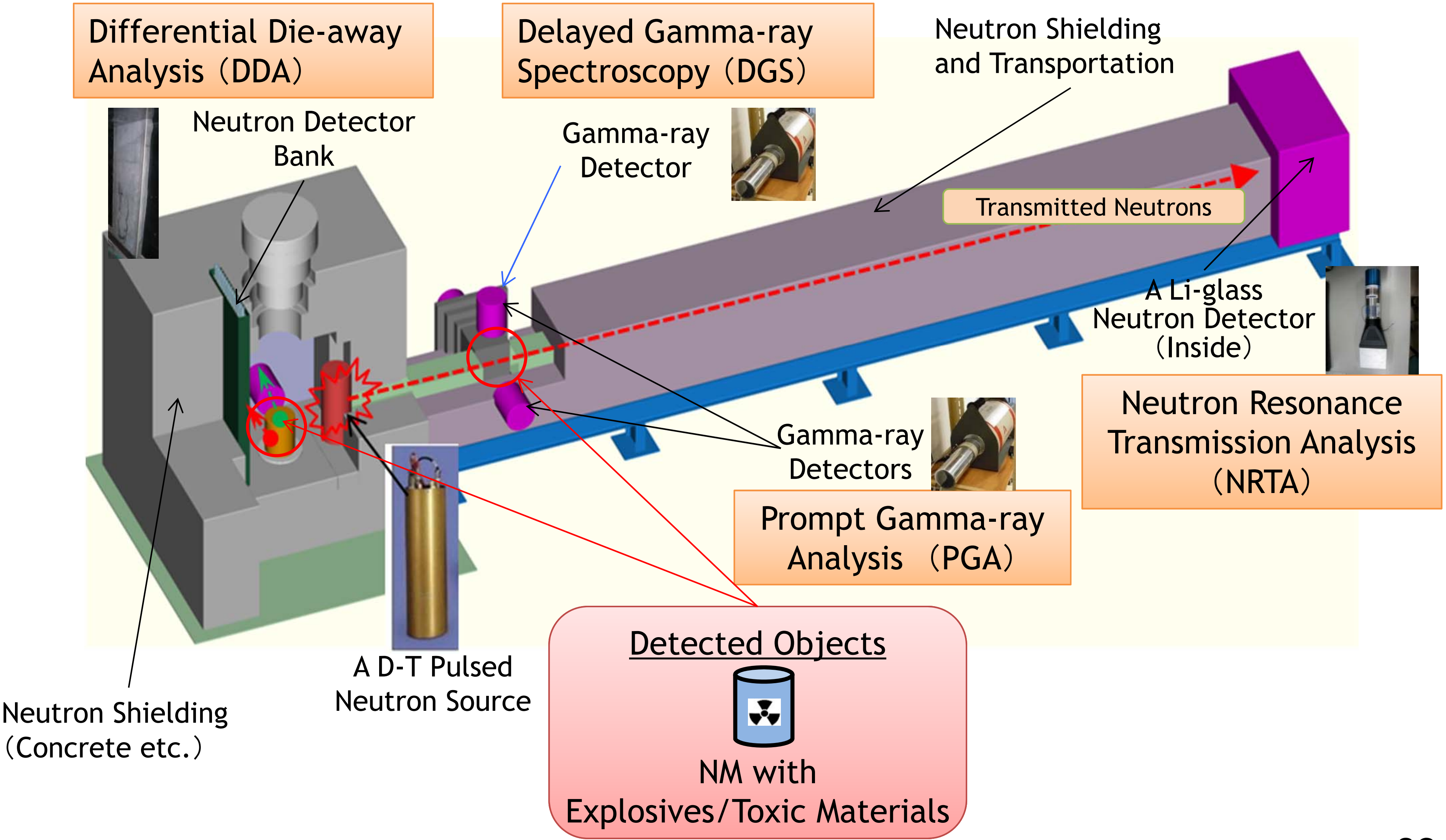




Hirofumi Tomikawa

Active (D-T Source) Neutron NDA System（1/2）

(for nuclear safeguards/ nuclear security)



Hirofumi Tomikawa

Active (D-T Source) Neutron NDA System（2/2）

Active NDA Techniques	What Quantified / Identified
DDA: Differential Die-away Analysis	^{239}Pu-effective
DGS: Delayed Gamma-ray Spectroscopy	Ratio of ^{235}U/^{239}Pu/^{241}Pu
NRTA: Neutron Resonance Transmission Analysis	Quantity of each of U/Pu isotopes
PGA/ NRCA Prompt Gamma-ray Analysis Neutron Resonance Transmission Analysis	Existence of explosives / toxic materials

The viability of the Iran nuclear accord (JCPOA) will depend on effective IAEA safeguards.

Some critics contend that large bulk handling facilities are inherently incapable of being adequately safeguarded because of the problem of material unaccounted for (MUF) and other issues.

They argue that the IAEA will not be able to adequately safeguard the Natanz Enrichment facility in the future.

- **Natanz is planned for 190,000 SWU. This will be allowed after the JCPOA limits come off in 15 years.**
- **Iran should be persuaded to rely instead on the international marketplace.**
- **But the IAEA will need to anticipate that Iran will employ IR-8 model centrifuges in large numbers.**

The criticism fails to take into account the IAEA's multi-layered safeguards tools and new technologies.

- **At Natanz and Fordow, modern technologies include electronic seals and the on-line enrichment Monitor (OLEM) to provide continuous measurements directly to the IAEA.**

OLEM took many years to develop.

- **Given the time it takes, development of new technologies must start early on and be given sustained attention.**

Iran's restrictions on IAEA access to military sites puts more responsibility on the role of safeguards technology.

Plenary Discussion

Thank you for joining us.