National Nuclear Security Administration

National Nuclear Security Administration

Office of Nonproliferation and International Security (NIS)

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Nondestructive Assay of Spent Fuel for International Safeguards

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Safeguard nuclear material to prevent its diversion for illicit use.

Control the spread of WMD-related material, equipment, technology and expertise.

Verify nuclear reductions and compliance with international nonproliferation treaties and agreements.

Develop and implement nonproliferation and arms control policy.

International Nuclear Safeguards

- International nuclear safeguards comprise a set of technical measures to verify that civil nuclear materials are not diverted to undeclared uses
- Measures include inspections, nuclear material accountancy, containment and surveillance activities, and design information verification
- Carried out by the International Atomic Energy Agency (IAEA) subject to terms of safeguards agreements

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Next Generation Safeguards Initiative

Objective: To develop the policies, concepts, technologies, expertise, and international infrastructure necessary to strengthen and sustain the international safeguards system as it evolves to meet new challenges.

- Policy Development
- Concepts and Approaches
- ***Technology Development***
- Human Capital Development
- International Engagement

"We need more resources and authority to strengthen international inspections."

President Barack Obama

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Next Generation Safeguards Initiative

Safeguards Technology Development

- Sponsor safeguards technology development projects at U.S. National Laboratories

$14 million budget
11 National Laboratories
~ 35 projects in 2013

- Transition advanced technologies with medium-term safeguards applications from the laboratory into the field

- Organize field trials with international and domestic partners

- Strengthen safeguards technology development infrastructure at the U.S. National Laboratories

Spent Fuel Safeguards – Status Quo

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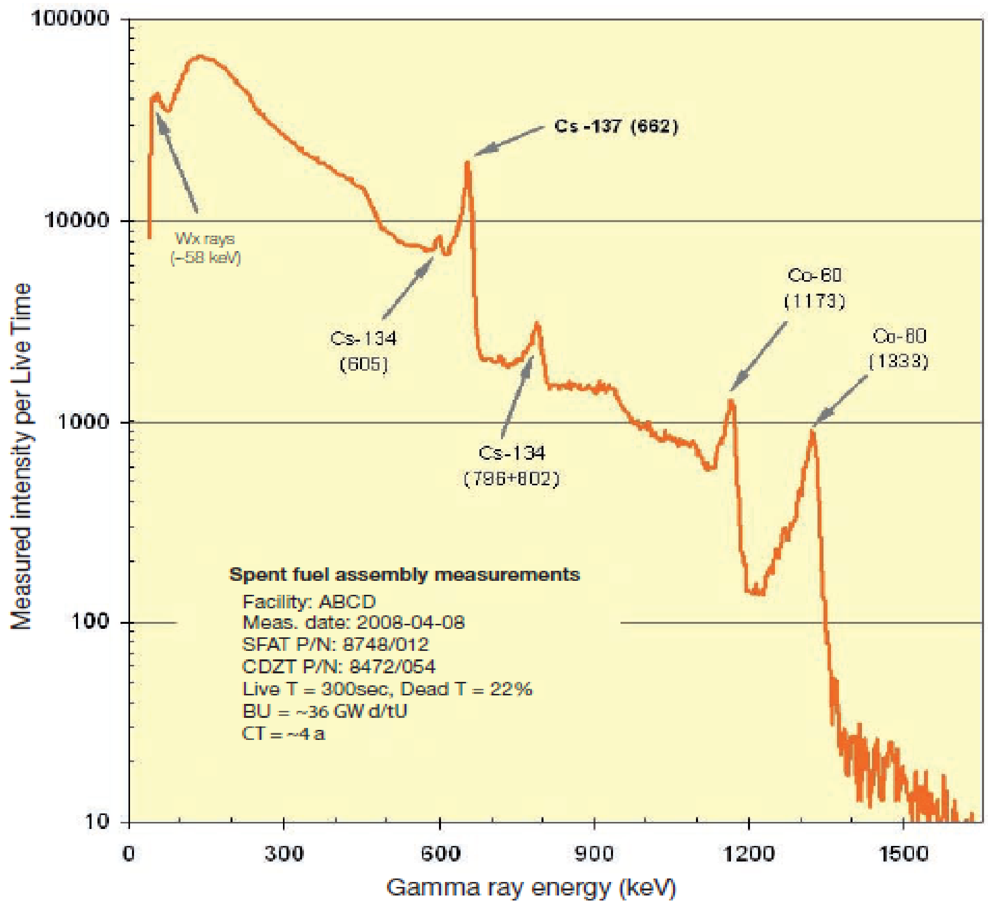
Spent Fuel Safeguards – Status Quo

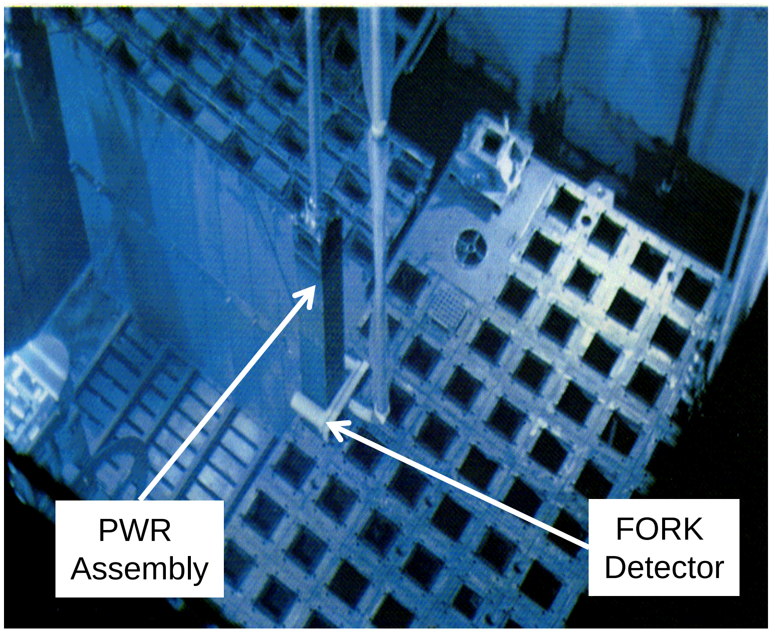
Spent Fuel Attribute Tester

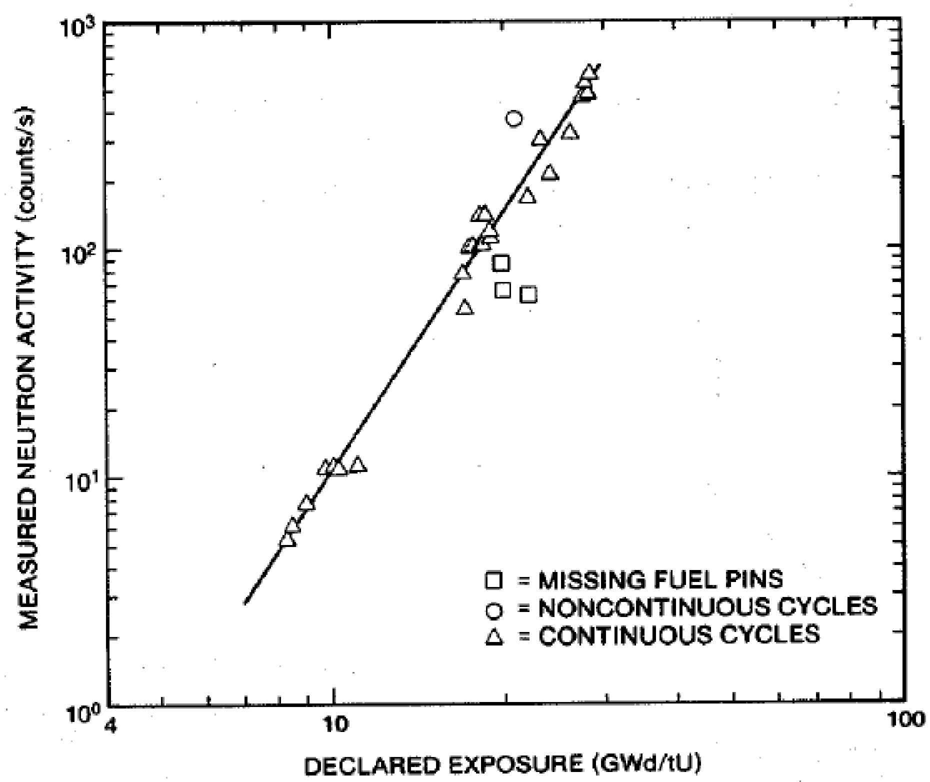
- Qualitative verification of spent fuel using fission product gammas



Spent Fuel Safeguards – Status Quo
Fork Detector

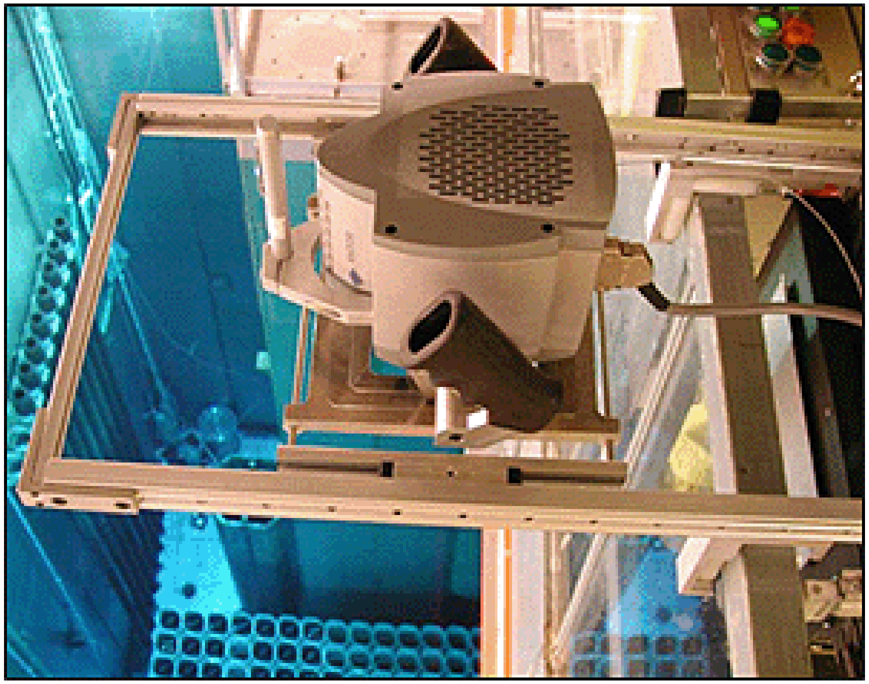
- Measures total neutrons and gross gammas to “verify” operating history of assembly (initial enrichment, burnup, cooling time)

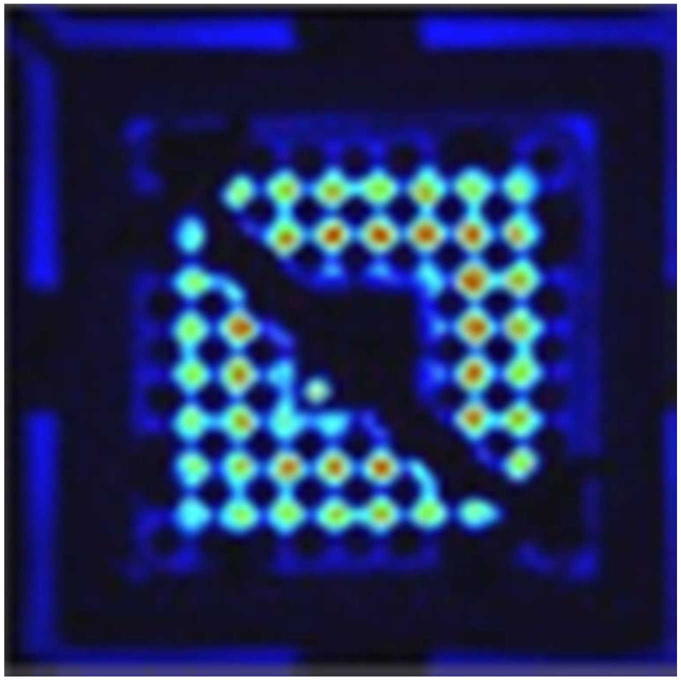




Spent Fuel Safeguards – Status Quo
Digital Cerenkov Viewing Device

- Measures intensity of near ultraviolet Cerenkov light in a spent fuel pond to detect and deter pin diversion (“partial defect”)





NGSI Spent Fuel NDA Project

Safeguards Objectives

- Primary Goal – to enable direct and independent quantification of Pu mass in spent fuel with an uncertainty of better than 5%
  - Input accountability at reprocessing facilities
  - Shipper/receiver difference
  - Special inspections

- Secondary Goal – to improve the toolkit of safeguards inspectors
  - Improved partial defect detection
  - Assure integrity of transport (e.g., fingerprinting)
  - Recovery from loss of “continuity-of-knowledge” (e.g., by determining initial enrichment, burn-up, cooling time and multiplication)
  - Improved understanding of the limits of spent fuel NDA

NGSI Spent Fuel NDA Project

Overview

- Underlying premise:

> While no existing NDA technique is capable of determining plutonium content singlehandedly to acceptable accuracy, plutonium quantification can be achieved through integration of several NDA techniques with complementary features.

- Five-year effort, begun in 2009:
  - Modeling and peer review (2009-2010)
  - Down-selection and system integration (2011)
  - Prototype development and field tests (2012-2014)

Phase 1
Modeling and Peer Review

- Systematic evaluation of 14 NDA techniques:

	Passive	Active
Neutron	**Total Neutron**	**^{252}Cf Interrogation with Prompt Neutron**
	Passive Neutron Albedo Reactivity	**Differential Die-Away**
	Self-integration Neutron Resonance Densitometry	**Delayed Neutrons**
	Differential Die-Away Self-Interrogation	**Lead Slowing Down Spectrometer**
	Coincident Neutron	**Neutron Resonance Transmission Analysis**
Gamma	**Passive Gamma**	**Delayed Gamma**
		Nuclear Resonance Fluorescence
X-Ray	**X-Ray Fluorescence**	

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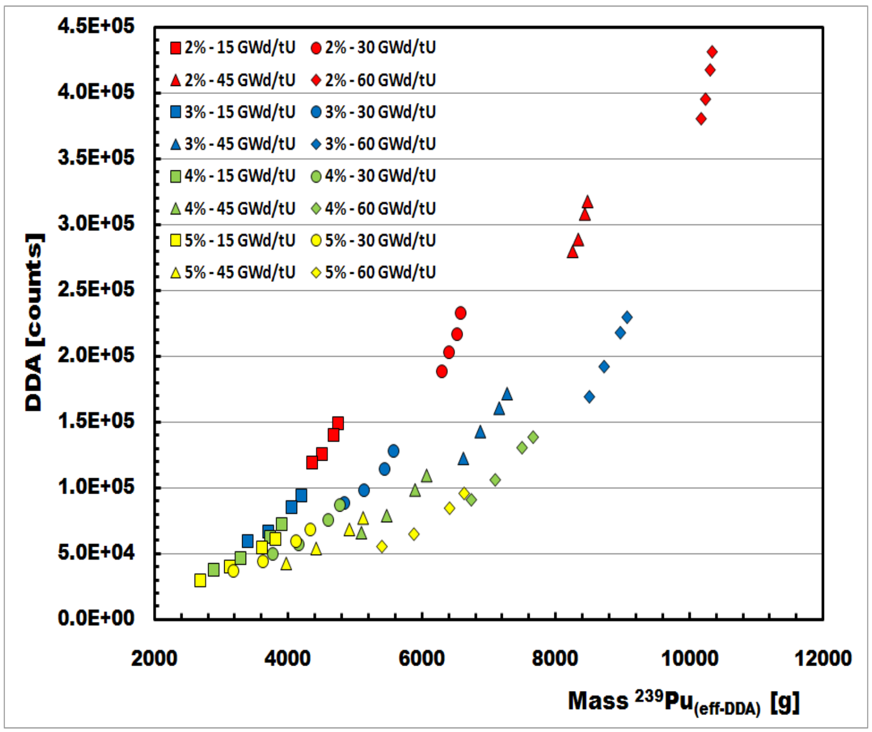
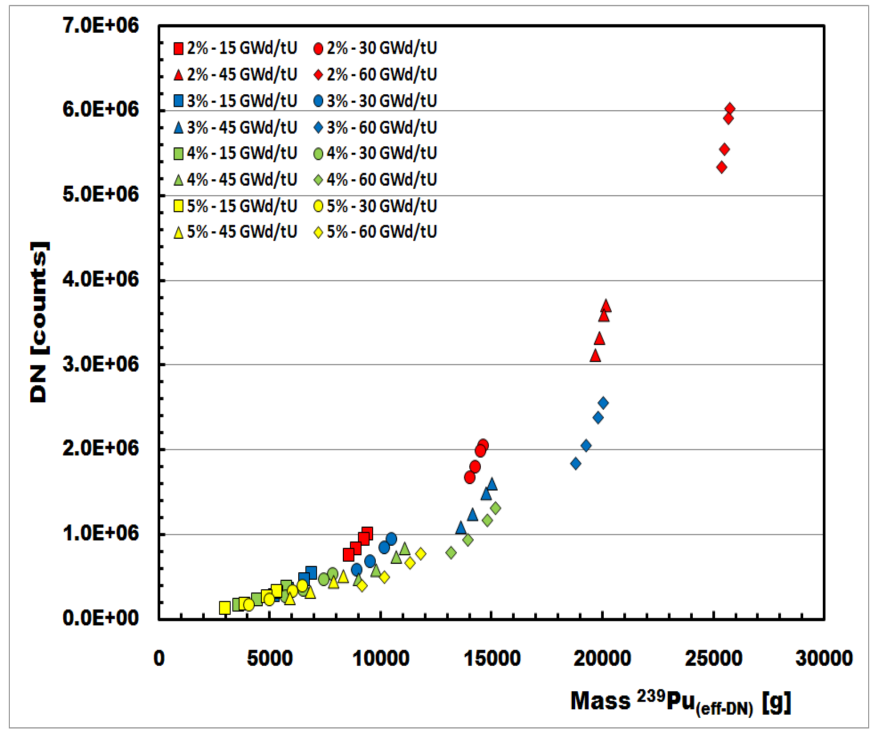
Phase 1

Modeling and Peer Review

- Simulated response of each against a common library of spent fuel assemblies



Differential Die-Away



Delayed Neutron

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Phase 1

Modeling and Peer Review

- External committee provided in-depth review of each technique

	PG	XRF	SINRD	DDSI	NM	PNAR-FC	PNAR-^{3}He	CIPN	AIPN
General Characteristics									
Time Required for Development	Short	Short	Short	Short	Short	Short	Short	Short	Short
Portable	Maybe	Maybe	Y	N	N	Y	N	N	N
Cost (High, Med, Low)[4]	L	M	M	M	M	L	M	H	L
Practical Implementation (Short Notice Inspection)	Y	N	Y	N	N	Y	N	N[5]	N
Hardware Maturity	High	High	High	High	High	High	High	High	High
Quantification Ability for Assemblies									
Elemental Pu	N	Y	N	N	N	N	N	N	N
^{239}Pu	N	N	Y	N	N	N	N	N	N
^{235}U	N	N	Y	N	N	N	N	N	N
^{241}Pu	N	N	Maybe	N	N	N	N	N	N
^{240}Pu	N	N	Maybe	N	N	N	N	N	N
$^{239}Pu_{eff}$	N	N	Y	Y	Y	Y	Y	Y	Y
FP absorbers	Maybe	Maybe	N	N	N	N	N	N	N
Other actinide absorbers	Maybe	Maybe	N	N	N	N	N	N	N
$^{239}Pu_{eff}$ Quantification Penetrability (# rows)	3-5	<1	3-4	9	~9	3-6	3-6	9	9
Burnup	Y	Maybe	Y	Y	Y	Y	Y	Y	Y
Initial Enrichment	N	N	Maybe	N	N	N	N	N	N
Cooling Time	Y	N	N	N	N	N	N	N	N
Pin Diversion Sensitivity[6] (High, Med, Low)									
Outer Region (rows 1-2)	None	None	H	M	?[7]	M	M	M	L
Middle Region (rows 3-5)	None	None	M	M	?	M	M	M	L
Center Region (rows 6-9)	None	None	None	H	?	L	L	M	L
Independence of (for Fissile Mass Quantification)									
Burnup	N	Y	Y	N	N	N	N	N	N
Initial Enrichment	N	Y	Maybe	N	N	N	N	N	N
Cooling Time	N	Y	Maybe	N	N	N	N	N	N
Priority for More Work	4	5	1	2	8	3	7	6	9

Phase 1
Modeling and Peer Review

- External committee provided in-depth review of each technique

	DDA	DN	DG	LSDS	NRF	NRTA	XRF	CIPN
General Characteristics								
Time Required for Development	Short	Short	Medium	Medium	Long	Long	Short	Short
Portable	N	N	N	N	N	N	Maybe	N
Cost (High, Med, Low)[8]	H	H	H	H	H	H	M	H
Practical Implementation (Accuracy)	Y	Y	Y	N	N	N	Y	Y[9]
Hardware Maturity	High	High	High	High	Low	High	High	High
Quantification Ability for Assemblies								
Elemental Pu	N	N	N	N	N	N	Y	N
^{239}Pu	N	N	Maybe	Maybe	Y	Y	N	N
^{235}U	N	N	Maybe	Maybe	Y	Y	N	N
^{241}Pu	N	N	Maybe	Maybe	Y	Y	N	N
^{240}Pu	N	N	N	Maybe	Y	Maybe	N	N
$^{239}Pu_{eff}$	Y	Y	Y	Maybe	Y	Maybe	N	Y
FP absorbers	N	N	Maybe	N	Maybe	Maybe	Maybe	N
Other actinide absorbers	N	N	Maybe	N	Maybe	Maybe	Maybe	N
$^{239}Pu_{eff}$ Quantification Penetrability (# rows)	9	9	5	9	9	5-7	<1	9
Burnup	N	N	N	N	N	N	N	Y
Initial Enrichment	N	N	N	N	N	N	N	N
Cooling Time	N	N	N	N	N	N	N	N
Pin Diversion Sensitivity[10] (High, Med, Low)								
Outer Region (rows 1-2)	M	M	H	M	M	H	None	M
Middle Region (rows 3-5)	M	M	M	M	M	M	None	M
Center Region (rows 6-9)	M	M	L	M	M	L	None	M
Independence of (for Fissile Mass Quantification)								
Burnup	N	N	Y	Y	Y	?[11]	Y	N
Initial Enrichment	N	N	Y	Y	Y	?	Y	N
Cooling Time	N	N	Y	Y	Y	?	Y	N
Priority for More Work	2	2	1	5	6	4	3	3

Phase 2
Down-selection and System Integration

- Down-selection criteria:
  - Quality of signal (e.g., dynamic range, penetration)
  - Hardware maturity
  - Simplicity/applicability
  - Robustness
  - Complementary features (hardware or physics)

Plutonium mass the primary goal

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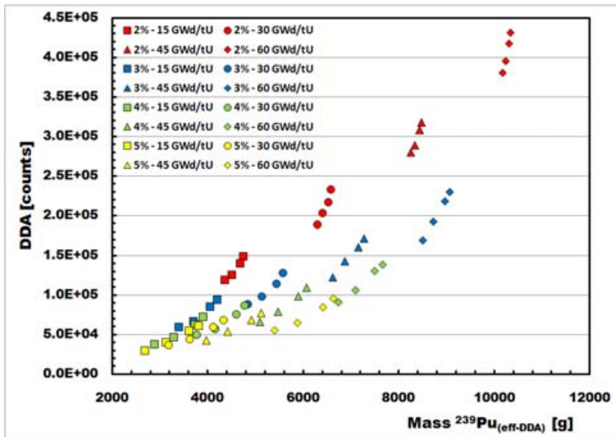
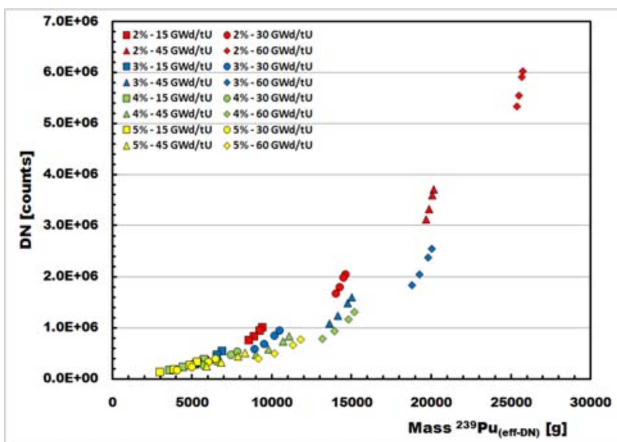
Phase 2

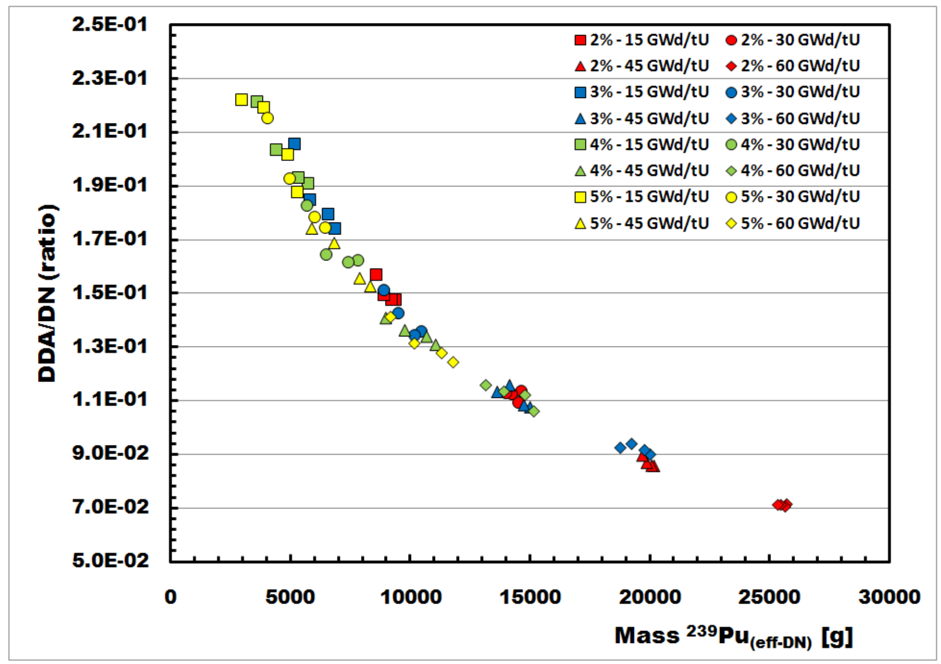
Down-selection and System Integration

Differential Die-Away





Delayed Neutron



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Phase 2

Down-selection and System Integration

System	Techniques	Key Attributes
1	- Passive Neutron Albedo Reactivity (PNAR) - Self-Interrogation Neutron Resonance Densitometry (SINRD) - Passive Gamma / Total Neutron	- Lightweight - Relatively low cost - Short measurement time - Robust
2	- Californium Interrogation Passive Neutron (CIPN) - Self-Interrogation Neutron Resonance Densitometry (SINRD) - Passive Gamma / Total Neutron	- Lightweight - Relatively low cost - Short measurement time - Robust
3	- Differential Die-Away Self Interrogation (DDSI) - Self-Interrogation Neutron Resonance Densitometry (SINRD) - Passive Gamma / Total Neutron	- Relatively heavy - Intermediate cost - Longer measurement time - Robust
4	- Delayed Neutron (DN) - Differential Die-Away (DDA) - Delayed Gamma (DG) - Passive Gamma / Total Neutron	- Relatively heavy - Relatively high cost - Longer measurement time - Less robust - Potential for high accuracy

Phase 3
Prototype Development and Field Trials

- Prototype development schedule:

Technique	Fabrication
Self-integration Neutron Resonance Densitometry (SINRD)	2012
^{252}Cf Interrogation with Prompt Neutron (CIPN)	2012-13
Passive Neutron Albedo Reactivity (PNAR)	2012-13
Differential Die-Away Self-Interrogation (DDSI)	2013
Differential Die-Away (DDA)	2014
Differential Die-Away (DDA) Delayed Neutron (DN) Delayed Gamma (DG) } integrated	?

Phase 3
Prototype Development and Field Trials

- Field trial schedule:

Technique	Partner	Date
Self-integration Neutron Resonance Densitometry (SINRD)	ROK/Japan	2013
^{252}Cf Interrogation with Prompt Neutron (CIPN)	ROK	2013
Passive Neutron Albedo Reactivity (PNAR)	Japan	2013
Differential Die-Away Self-Interrogation (DDSI)	ROK	2014
Differential Die-Away (DDA)	Sweden	2014
Differential Die-Away (DDA) Delayed Neutron (DN) Delayed Gamma (DG) } integrated	?	?

Non-Safeguards Applications

- Potential benefits to facility operators:
  - Determination of burn-up credit (so fuel can be stored and shipped more efficiently)
  - Optimization of reactor core reloading
  - Optimization of assembly selection for reprocessing
  - Determination of heat load in a geological repository

Measurement of multiplication, IE, BU, and CT could be integrated into normal fuel management

Summary

- Routine safeguards measurements for spent fuel assemblies rely on indirect measurements, computer simulation, and operator-supplied information.
- New technologies would improve input accountancy, recovery from loss of continuity-of-knowledge, or containment measures.
- While no single NDA technique can likely determine plutonium content singlehandedly to acceptable accuracy, integration of several techniques will help.
- Project will also advance our understanding of capabilities and limitations in the area of spent fuel NDA.

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Thanks

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