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National Nuclear Security Administration

Active Interrogation of Spent Fuel

M. T. Swinhoe, H. Trellue and A. Favalli

Los Alamos National Laboratory

NUCLEAR SAFEGUARDS
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OBJECTIVE/GOALS:

- Note that 240,000 MT of spent fuel are in storage worldwide (~20,000 MT Pu), 90% in storage ponds (2009*)

- The purpose of the spent fuel Nondestructive Assay (NDA) research is to develop and test integrated technologies to improve NDA measurements of spent fuel assemblies.

- The technical goals of the project are:

  1. *Verify **initial enrichment, burn-up and cooling time** of facility declaration*
  2. *Detect **diversion or replacement of pins**,*
  3. *Estimate **Pu mass** in spent fuel [which is also a function of the variable in (1)],*
  4. *Estimate **heat** emitted from assembly*
  5. *Measure **reactivity** (multiplication) of each assembly.*

***International Panel on Fissile Materials** Managing Spent Fuel from Nuclear Power Reactors Experience and Lessons from Around the World **September 2011 ISBN 978-0-9819275-9-6**

Active Interrogation

Principles of the Differential Dieaway Method

- **Active technique** that uses neutron pulses (generally from a D-T-neutron generator) to induce fission in nuclear materials (e.g.^{235}U, ^{239}Pu, ^{241}Pu) present in (spent) nuclear fuel.
- **Interrogation system:** generally moderating materials to exploit thermal neutron induced fission
- **Detection:** detectors are generally ^{3}He-based proportional counters.
- **Principle**: following the interrogation pulse the neutron fission populations die-away with time. Die-away time is function of fissile content (and multiplication in spent nuclear fuel) in the materials under assay. Differential signals refers to the much slower die-away signal when nuclear material is assayed compared with the die-away signal of neutrons of the interrogation system without nuclear material.

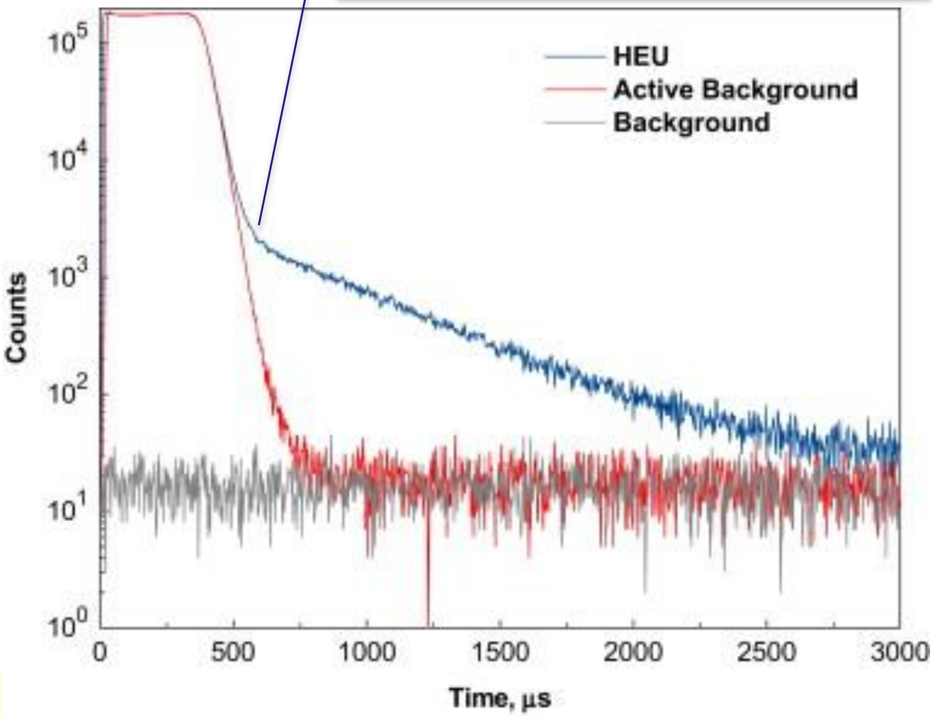
J. T. Caldwell et al, LANL , LA-10774-MS, 1986; A.Favalli et al, IEEE TNS, 2009; R. C. Runkle,et al. NIM 663, 2012.

Classical DDA

Principles

Useful data >500μs

DDA Signal: neutron detectors are synchronized with each interrogation pulse. DDA curves are collected by recording the fission counts as function of the time after each neutron interrogation pulse, and by summing them over the measurement time of the assay.



Note: passive background & active background, due to neutron generator source

DDA example: Die-away neutron signature following interrogation of 9.4 kg of HEU in a wood box[1]. DT-generator @ 300 Hz, 10% duty cycle, 4×10^7 n/s

(1) R. C. Runkle, D. L. Chichester, S. J. Thompson, NIM 663, 2012.

DDA for Spent Nuclear Fuel assay

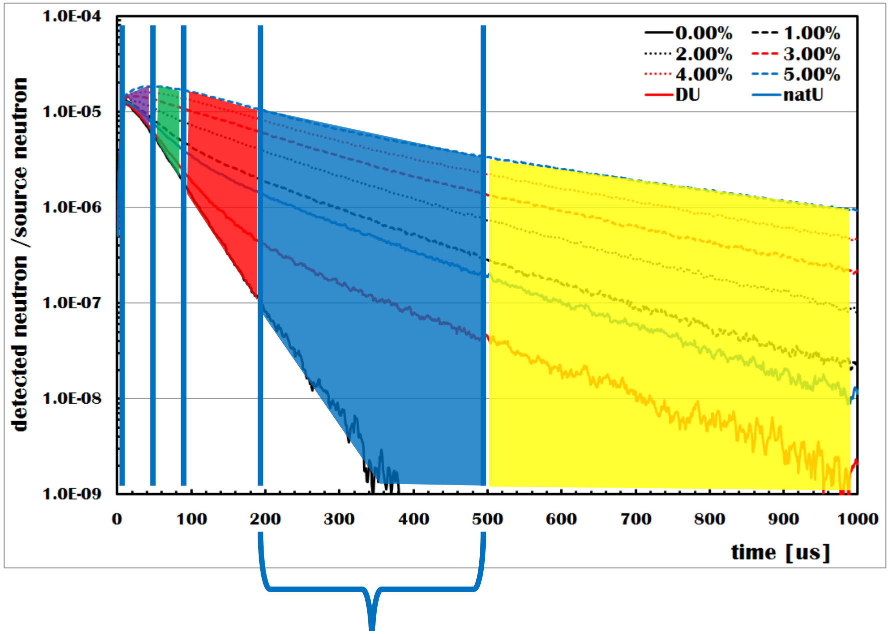
One GOAL: to estimate the fissile mass in a spent fuel assembly

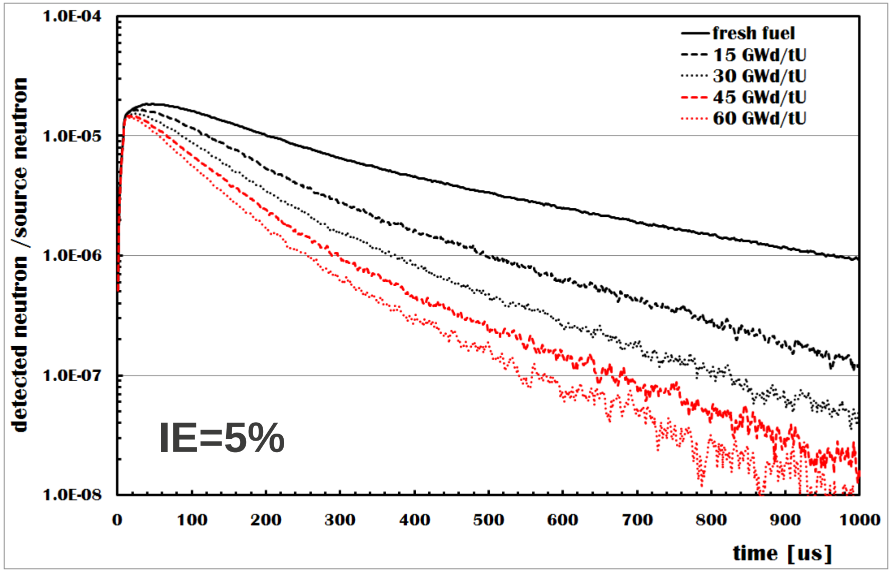
- DDA methods in highly multiplying environments.
- Use a short pulse (~20-50 µs) of neutrons from external DT neutron generator
- Induced neutron population dies away on the order of hundreds of microseconds
- Measured signal reveals properties of the fuel assembly, primarily multiplication, and implicitly a function of initial enrichment (IE), Burnup (BU), and Cooling Time(CT) of the spent nuclear fuel assembly
- Monte Carlo results have showed the Pu content in spent nuclear fuel assembly with high accuracy

DDA for Spent Nuclear Fuel Assay:

fresh nuclear fuel versus spent nuclear fuel

- **Fresh fuel** : DDA response increases (die-away time is longer) with increasing fissile content
- **Spent fuel** : DDA response decreases (die-away time is shorter) with higher burn-up (i.e. more neutron absorbers present)



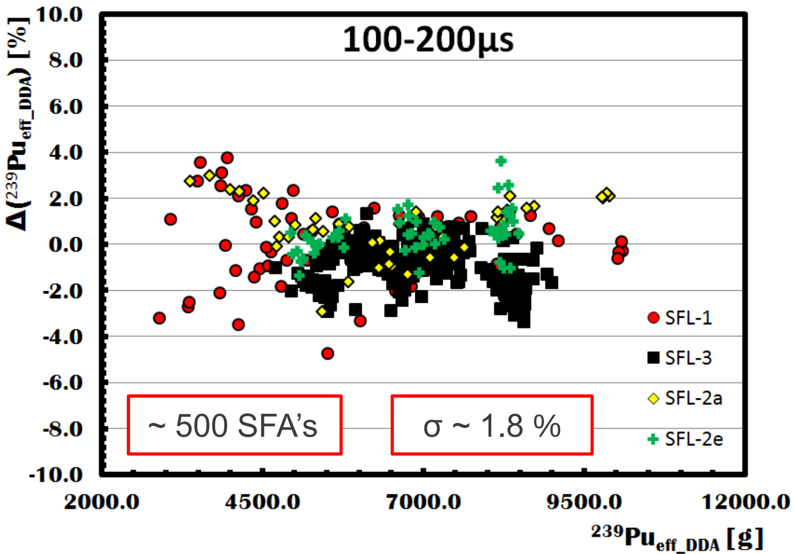


DDA signal = integral of counts in a given time domain (without the contribution of burst neutrons)

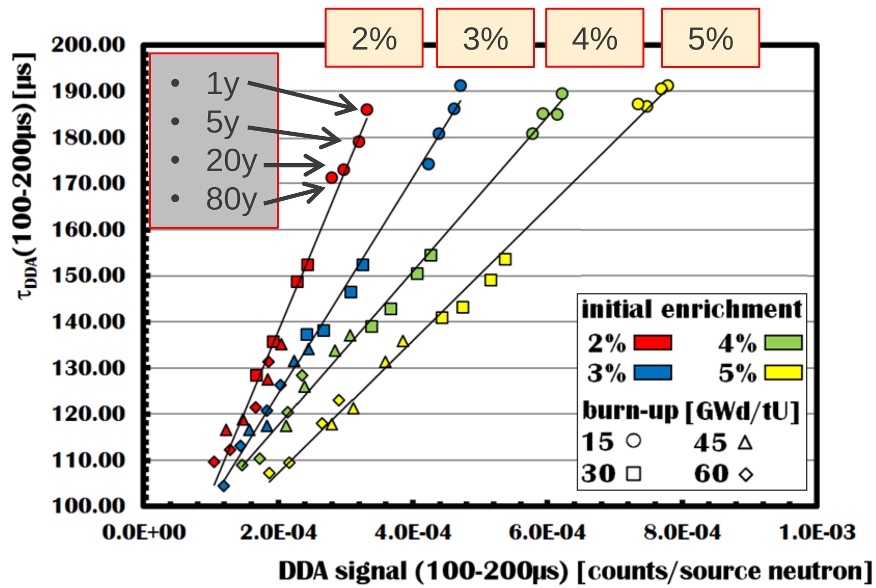
DDA for Spent Nuclear Fuel Assay

- Potential to determine various Spent Fuel Assembly (SFL) parameters:
  - multiplication (M_{act})
  - total Pu content (m_{Pu})
  - total fissile content ($^{239}Pu_{eff}$ ~ ^{235}U + ^{239}Pu + ^{241}Pu)
  - IE, BU

MCNPX simulations



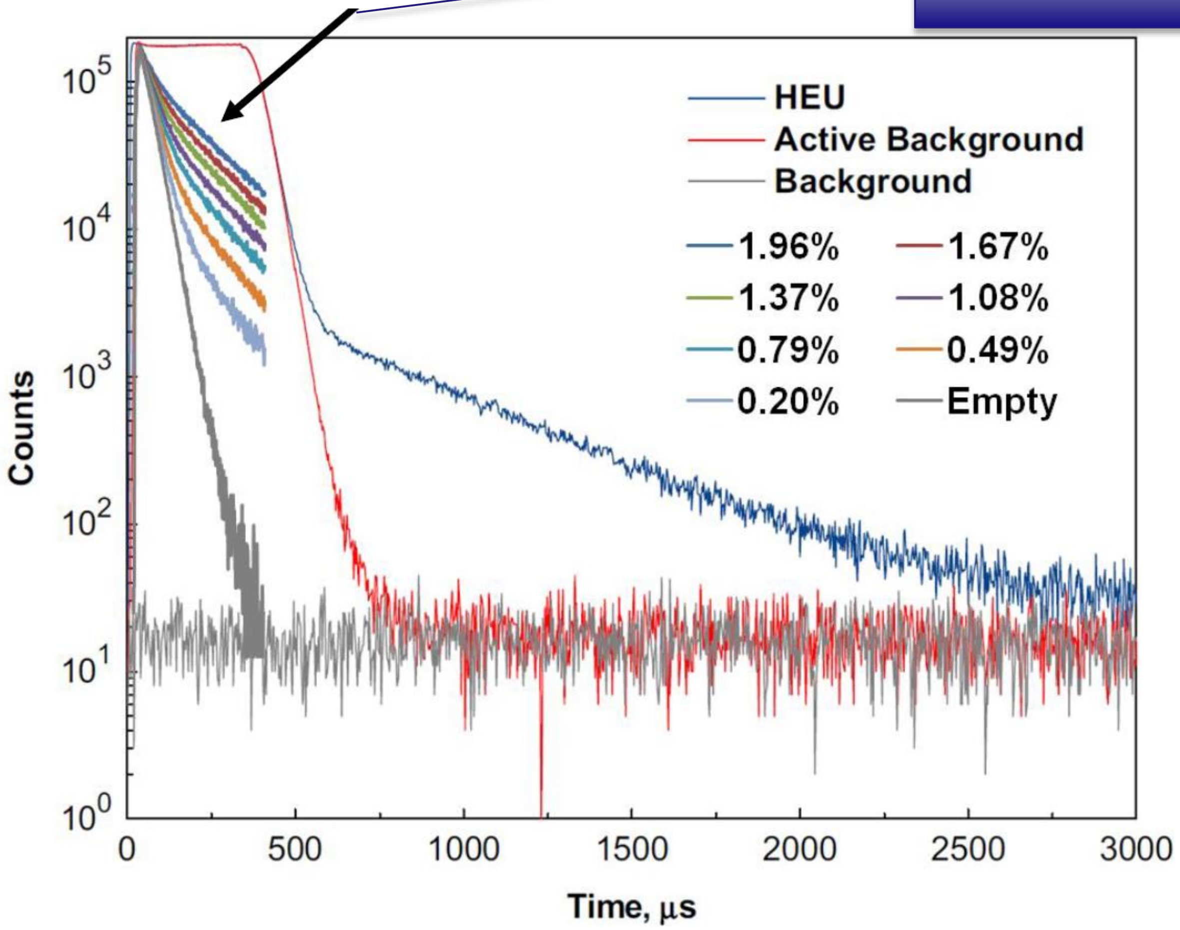
MCNPX simulations



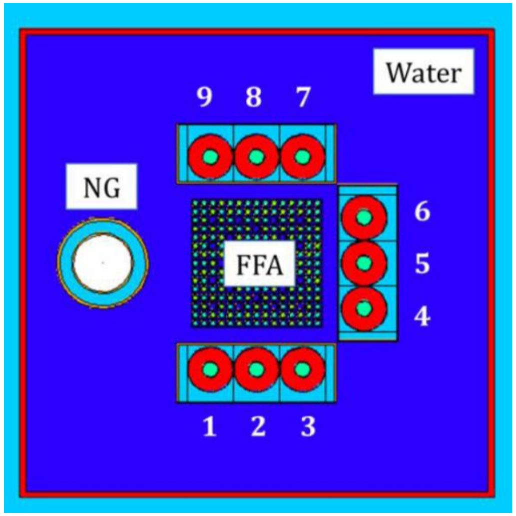
[1] V. Henzl et al., LA-UR-29224;[2] V. Henzl et al., JNMM 2012, vol.40

Towards DDA for Spent Nuclear Fuel assay:
DDA of fresh fuel with enrichment up to 1.96%

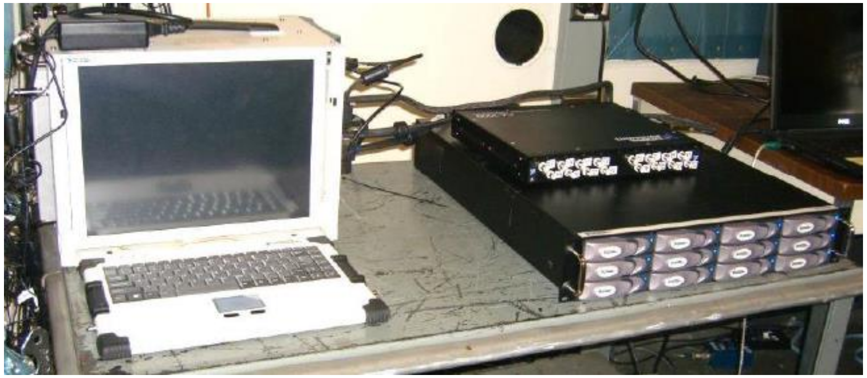
Useful data >50μs



Towards DDA for Spent Nuclear Fuel assay:
DDA of fresh fuel assemblies with enrichment up to 1.96%

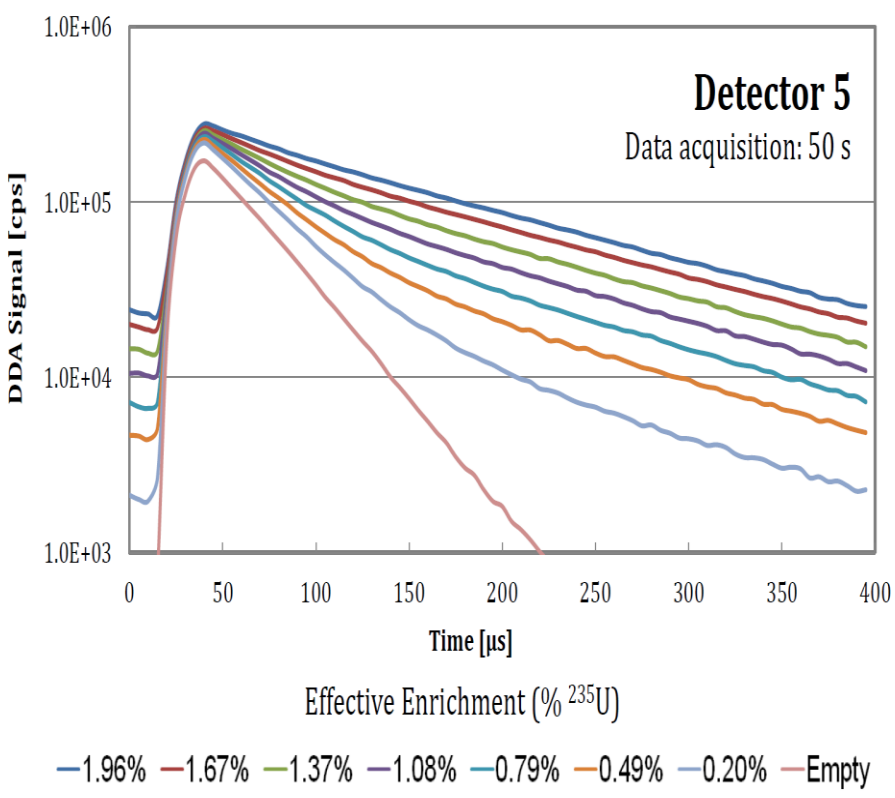


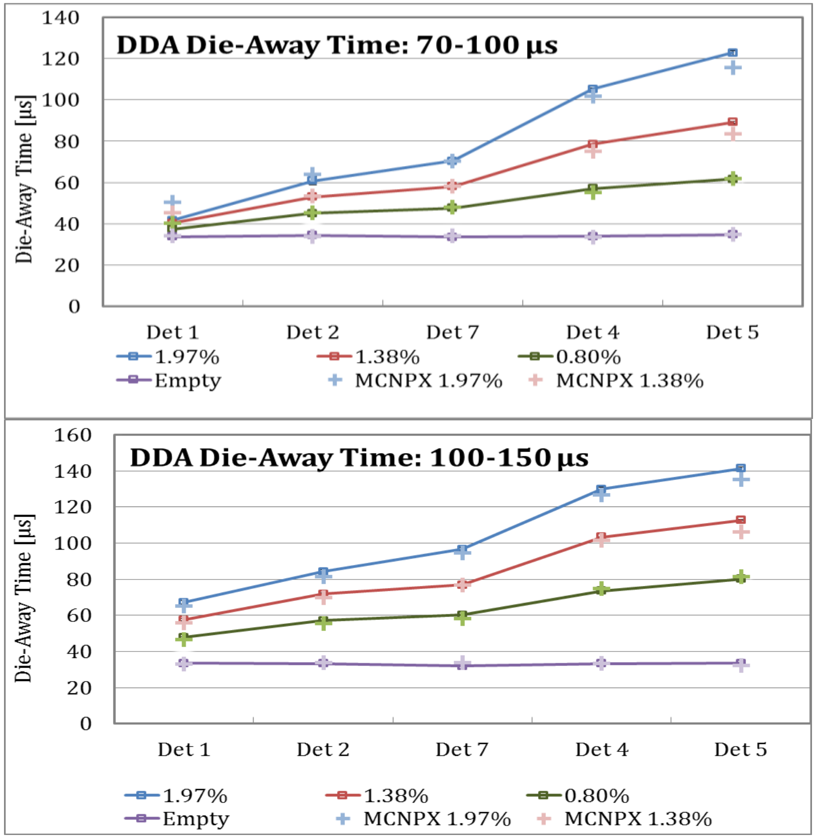
- PWR 15x15 fuel assembly with fresh fuel (enrichment from 1.97% ^{235}U to all depleted uranium, DU)
- 9 ^{3}He detectors in 3 stainless steel open-top enclosures
- 14.1 MeV DT neutron generator located inside of water-filled tank
- Time-dependent spatial data is collected from all 9 detectors using list-mode data acquisition system (built from commercial components).



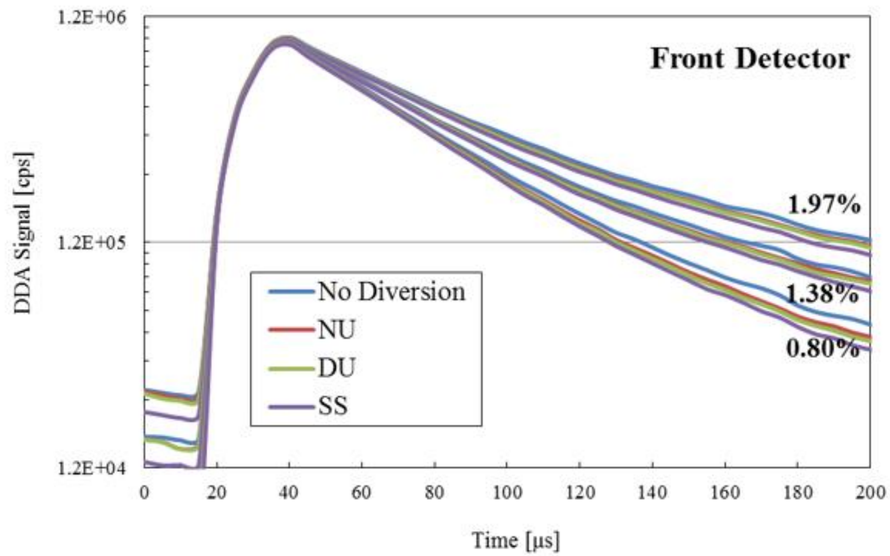
Towards DDA for Spent Nuclear Fuel assay:
DDA of fresh fuel assemblies with enrichment up to 1.96%

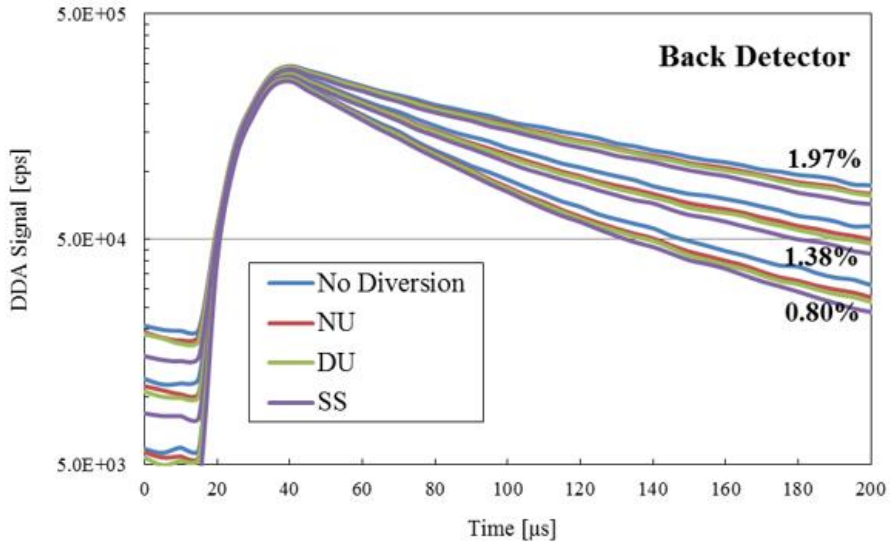
Experimental Data as a Function of Enrichment (counting rate and dieaway time compared to simulation)





DDA of fresh fuel assemblies with missing pins





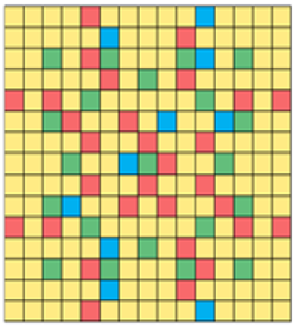
Red = LEU fuel rod

yellow = DU

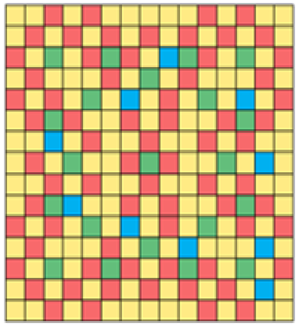
Green = guide tube position

Blue = Diversion position (natural, depleted, or stainless steel rod), (For the No Diversion scenario, blue = LEU.)

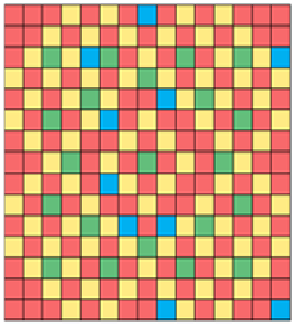
0.80%



1.38%

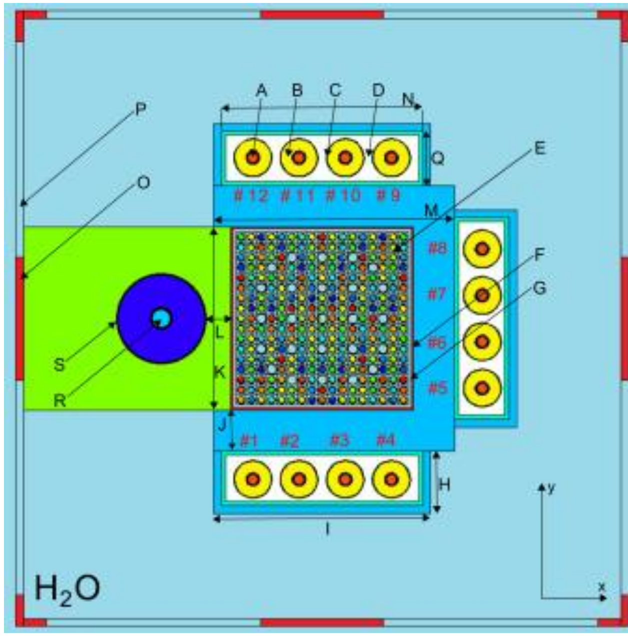


1.97%



Designing DDA for Spent Nuclear Fuel assay

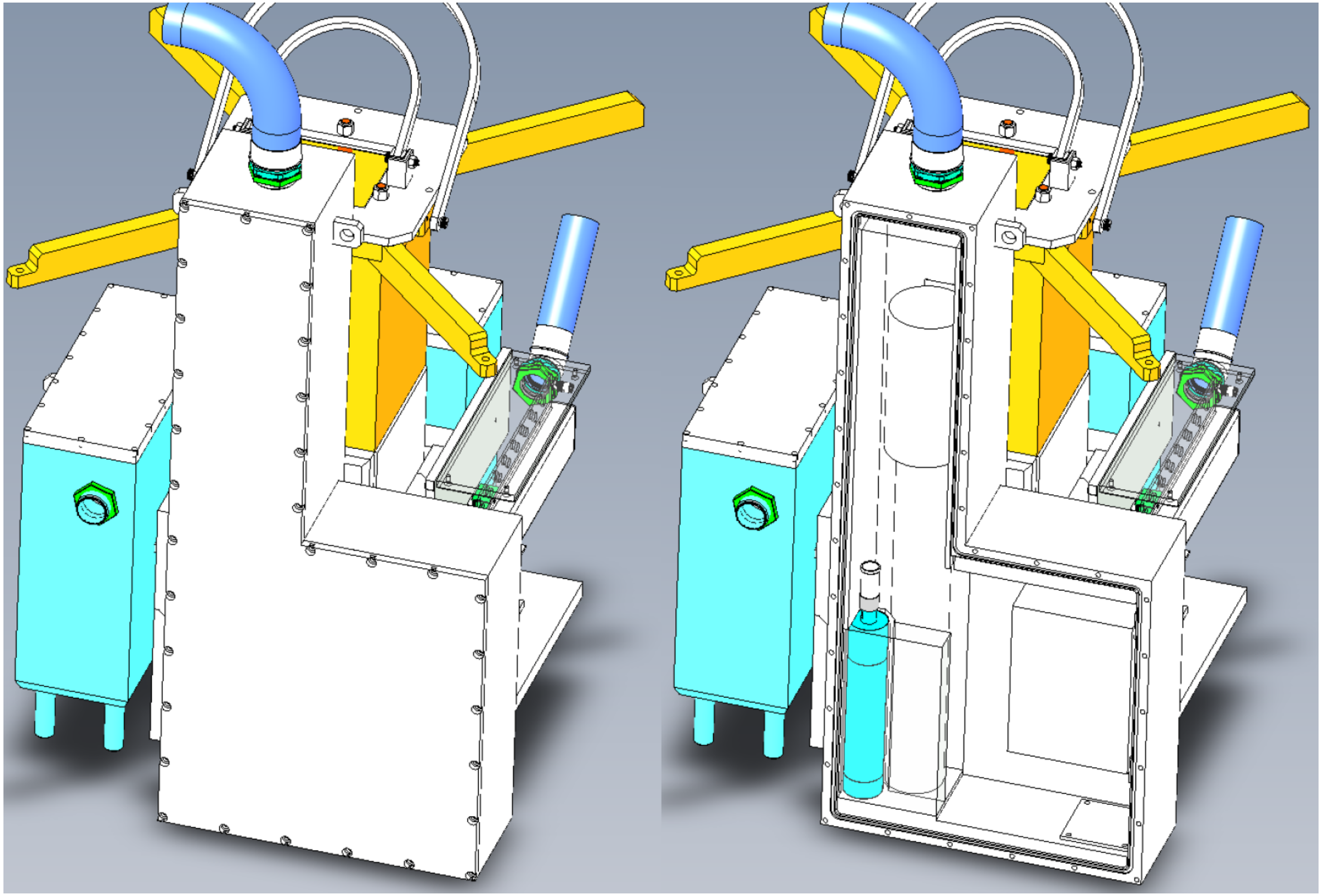
- Neutron Generator pulse width 50 µs (1kHz rep rate) @~3×10^8 n/s, emission yield
- Gamma shielding for neutron generator (also source tailoring) with W
- 12 ^{3}He detectors, active length 5 cm, 1.27 cm diameter, 7.5 atm ^{3}He pressure
- ^{3}He moderator: 1.4 cm polyethylene with 0.1cm Cd wrap
- 5 cm thick lead shielding for ^{3}He detectors
- Count rate capability 2 MHz with deadtime correction
- Cd liner around fuel.
- For both BWR and PWR fuel assemblies (different guides)



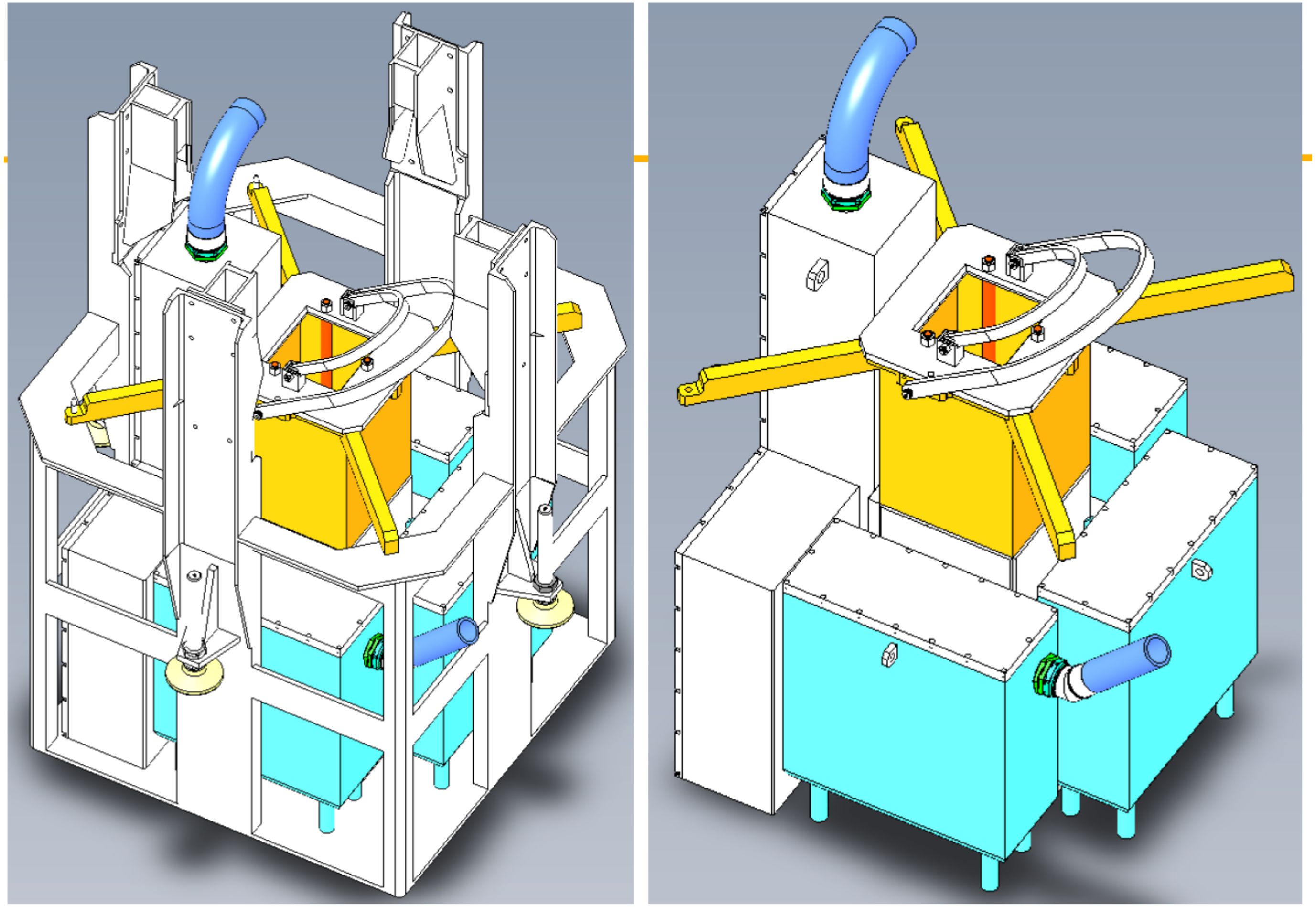
MCNP Design(1)

[1] T. Martinik, et al., Nuclear Instruments and Methods A, Vol.281,(2016)

DDA design for Spent Nuclear Fuel assay

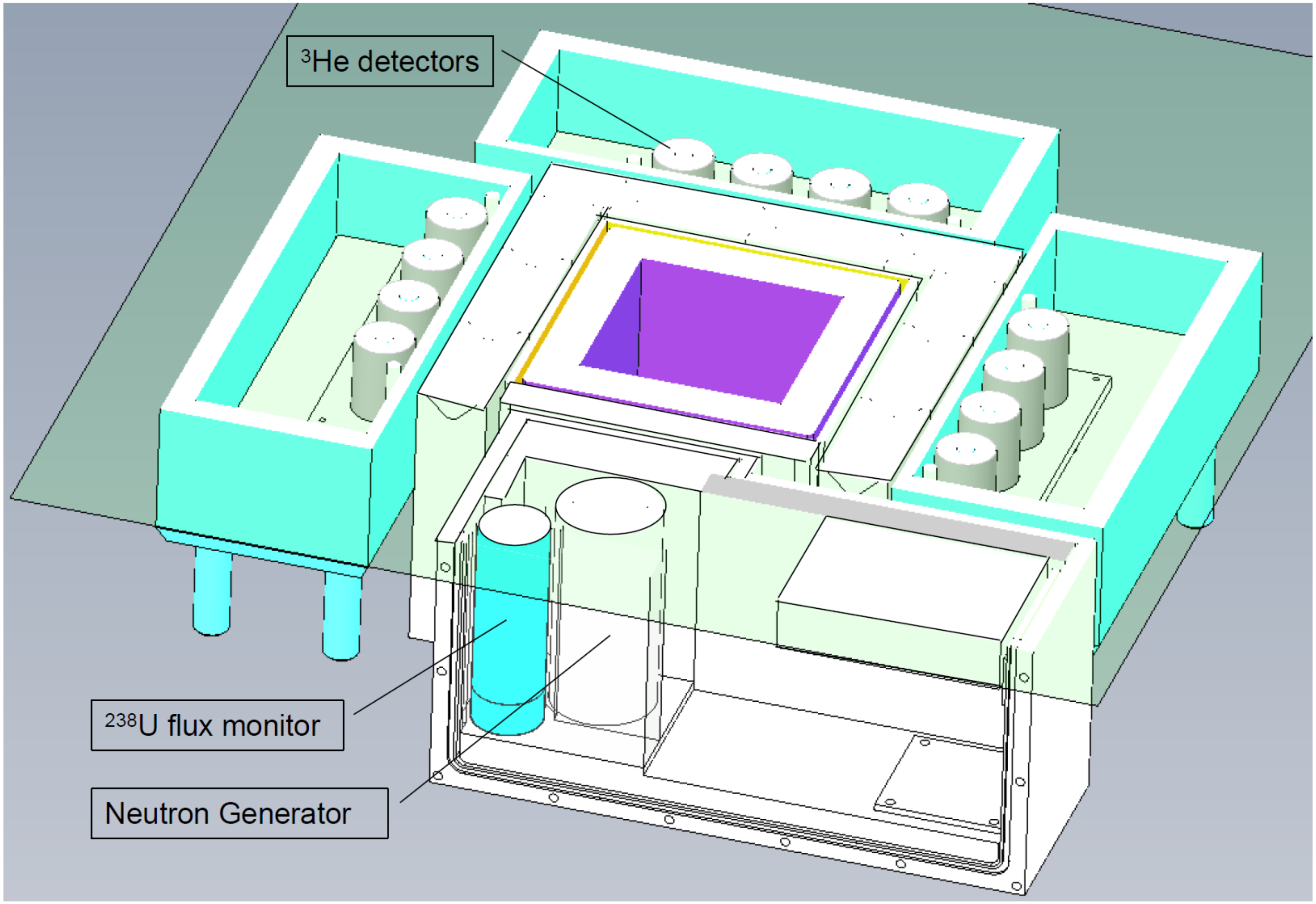


DDA design for Spent Nuclear Fuel Assay

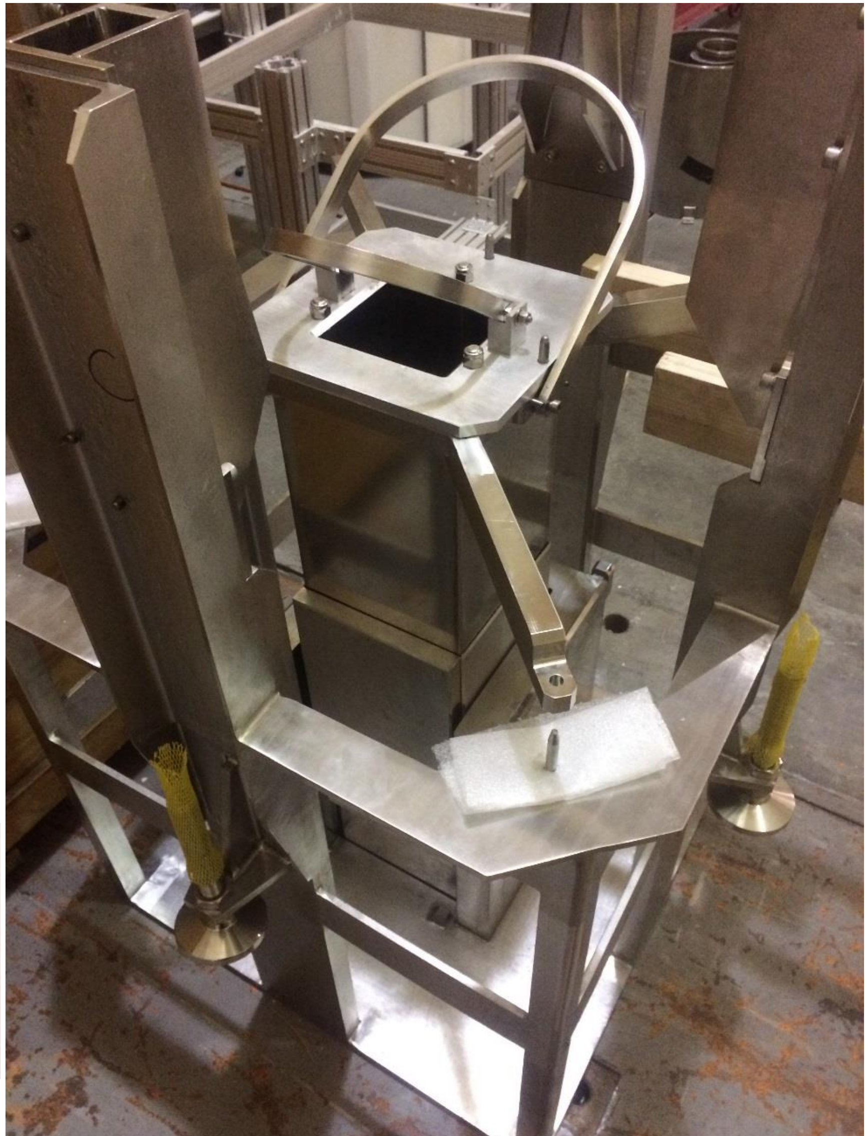


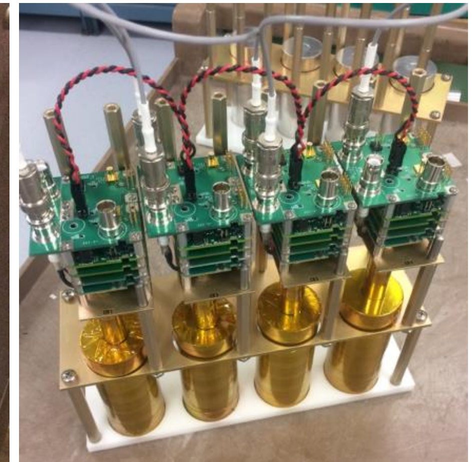
Being assembled at LANL, to be shipped to Sweden, Clab, for the measurement campaign in 2017

DDA design for Spent Nuclear Fuel Assay



DDA construction for Spent Nuclear Fuel Assay (Jan 2017)





Conclusion

- DDA method introduced and results discussed for fresh fuel assemblies.
- Design for nuclear spent fuel reported
- Spent fuel detector system is being tested with fresh fuel at Los Alamos National Laboratory
- Detector system will be shipped to Sweden, at Clab, Sweden interim spent nuclear facility. Measurements in Sweden are scheduled for 2017

Acknowledgements

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