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Title:	Direct Measurement of Initial Enrichment, Burn-up and Cooling Time of Spent Fuel Assembly with a Differential Die-Away Technique Based Instrument
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Direct Measurement of Initial Enrichment, Burn-up and Cooling Time of Spent Fuel Assembly with a Differential Die-Away Technique Based Instrument

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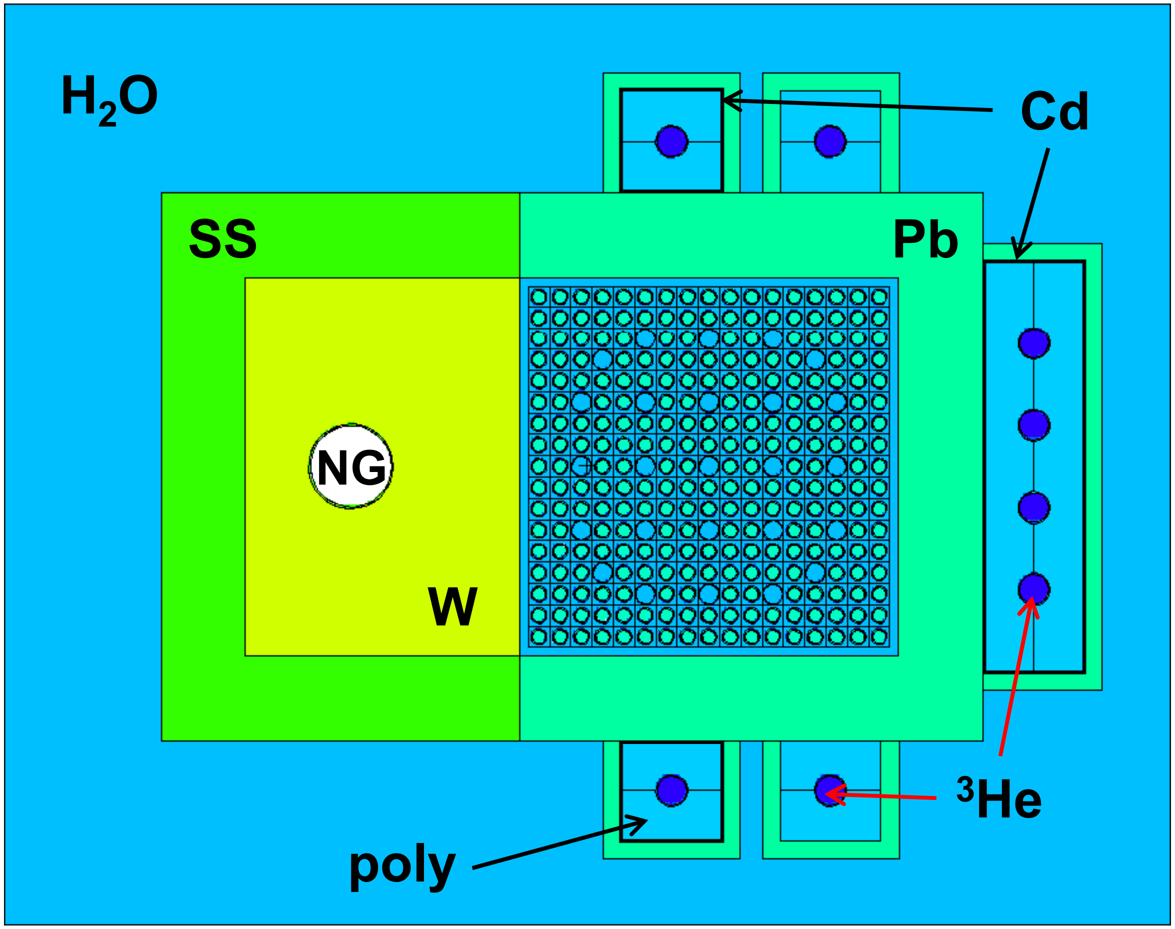
Outline (*i.e. what can DDA instrument do*)

- ❖ **Principle of operation of DDA instrument**
- ❖ **Determination of initial enrichment (IE) (σ<5%)**
- ❖ **Determination of burn up (BU) (σ~6%)**
- ❖ **Determination of cooling time (CT) (σ~20-50%)**
- ❖ **DDA instrument as a standalone device**

Integrated DDA+DN Instrument Design

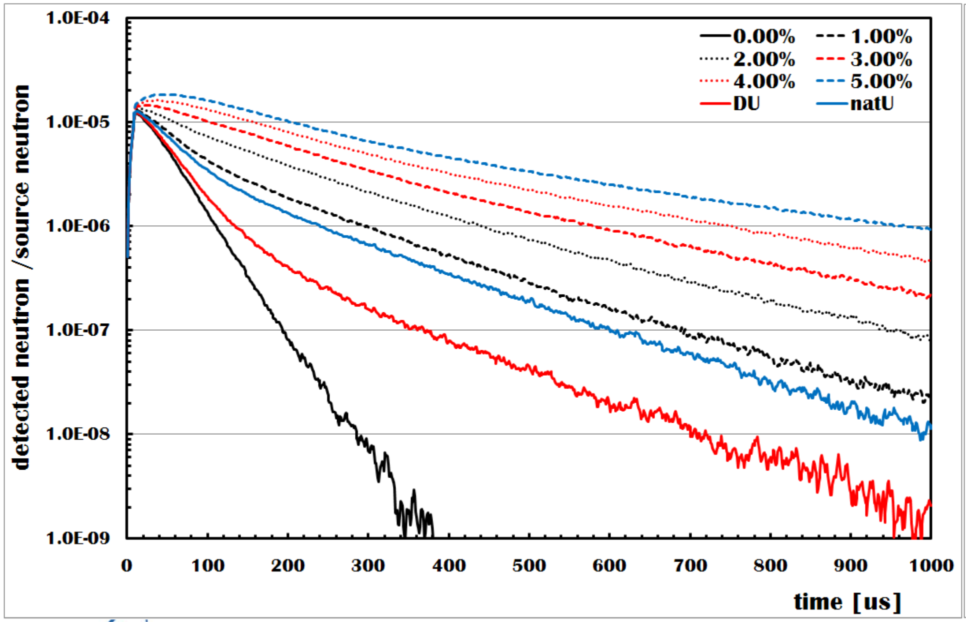


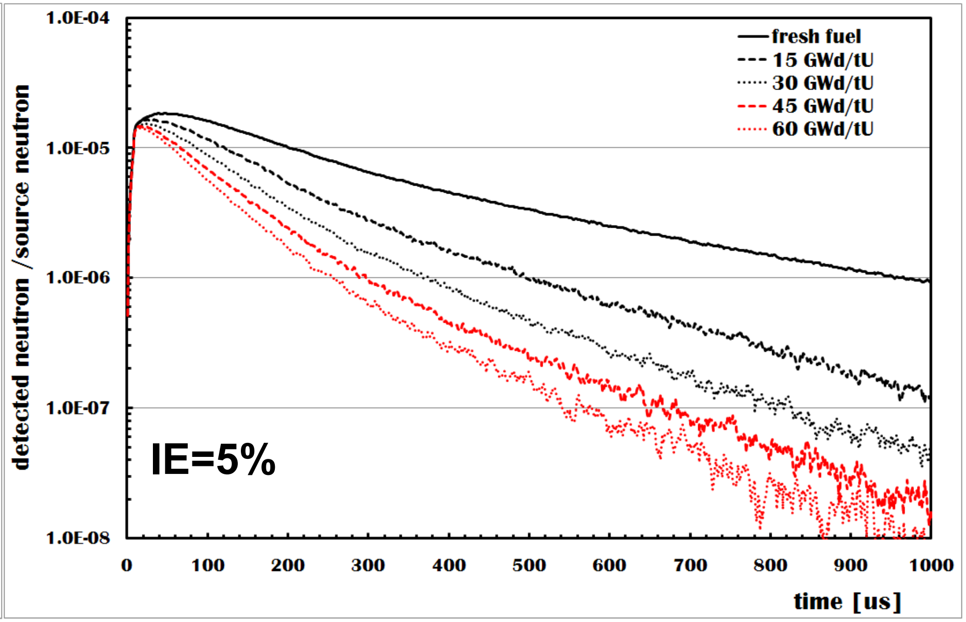
Design by P. Blanc & H. Menlove

- **DDA+DN Instrument Design**
  - ➢ *Neutron Generator* (NG) *d+t* based NG, 14 MeV
  - ➢ *Tungsten* (W) as a tailoring material
  - ➢ *Stainless steel* (SS) as a reflector
  - ➢ *6x ^{3}He w/ Cd* used for DDA (and DN),
  - ➢ *2x ^{3}He w/o Cd* to improve efficiency of DN instrument (i.e. DN only)

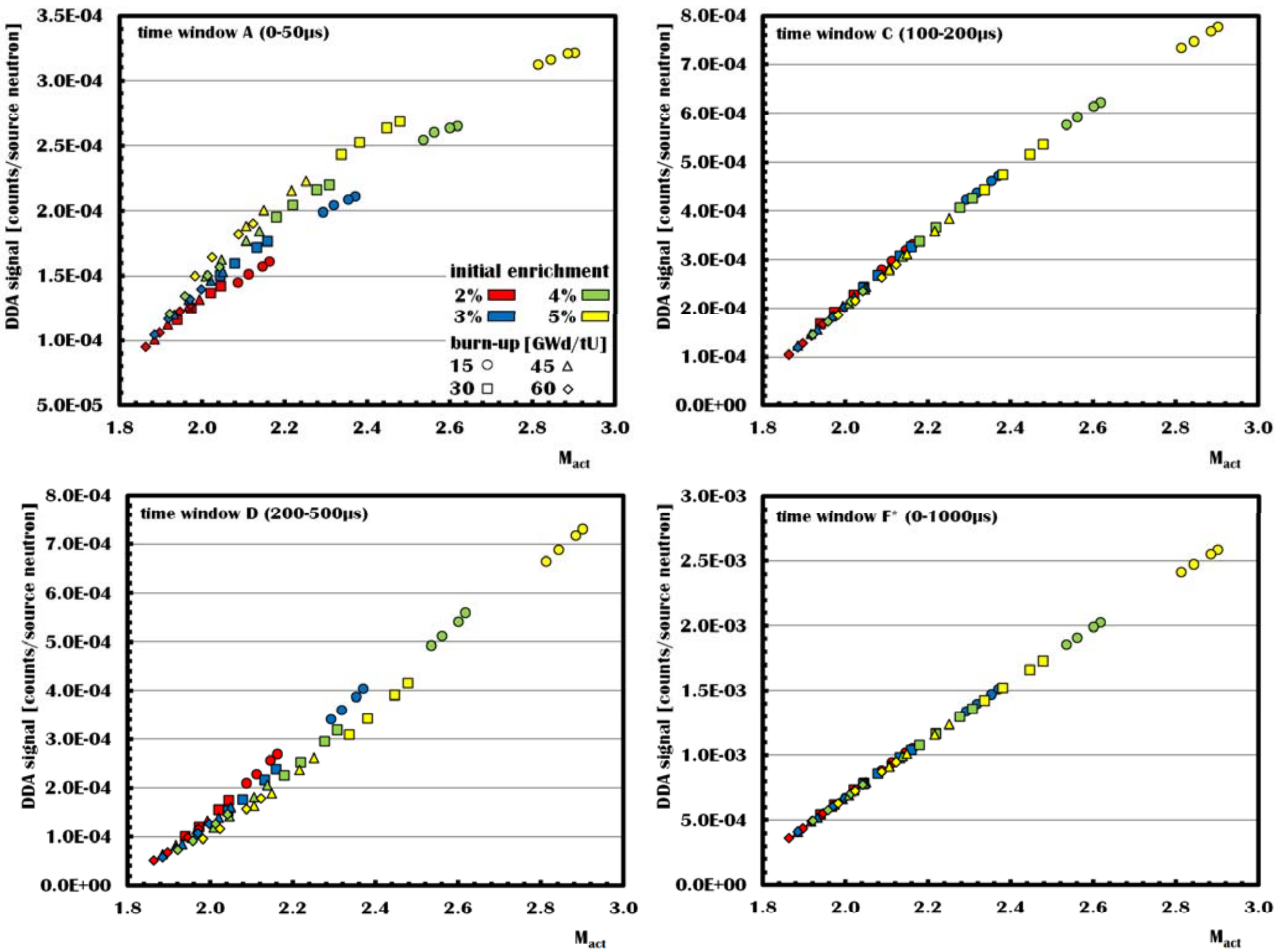
DDA response (*fresh fuel vs. spent fuel*)

- **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)**



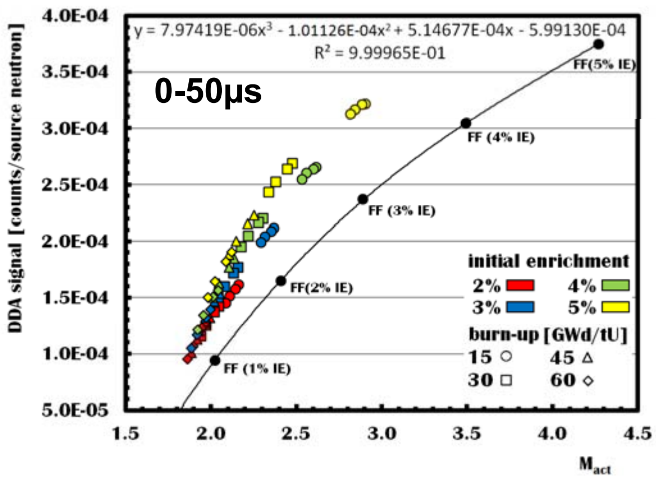


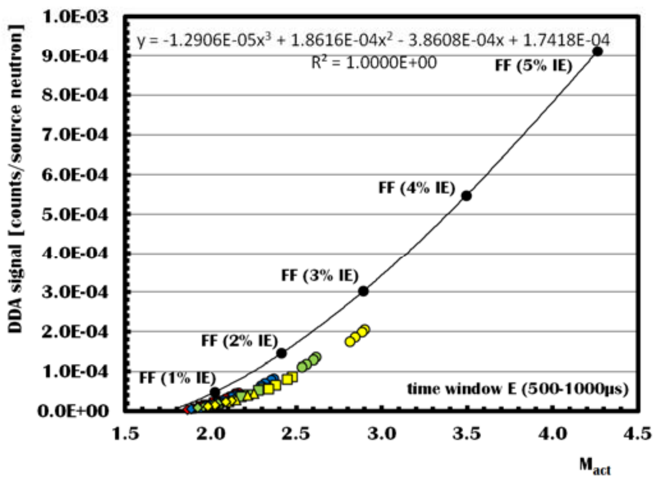
MCNPX simulation of DDA response (*evolution in time*)



- **DDA signal evolves in time depending on IE, BU, CT.**
  - ***BUT !!!***
  - overall it reflects the multiplication of the SFA
  - DDA signal ***can*** be a direct measure of ***multiplication***

DDA response & evaluation of neutron absorbers

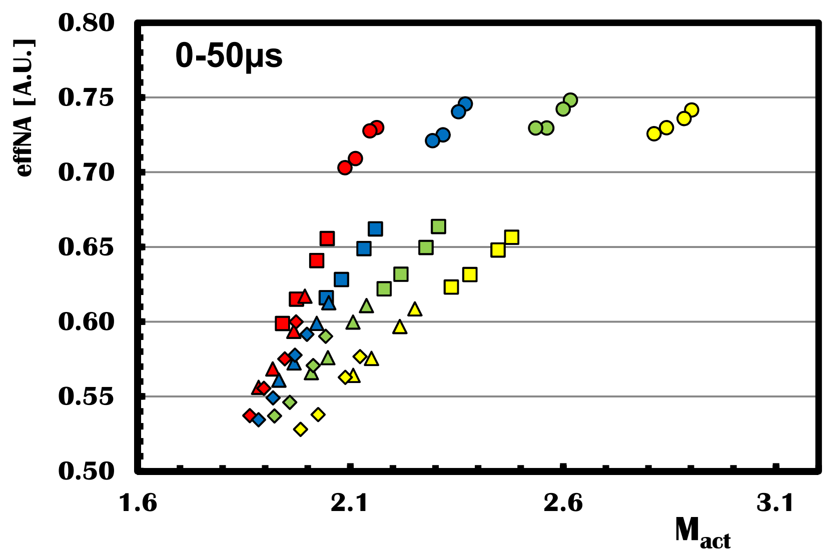




- “*effective neutron absorber coefficient*”:

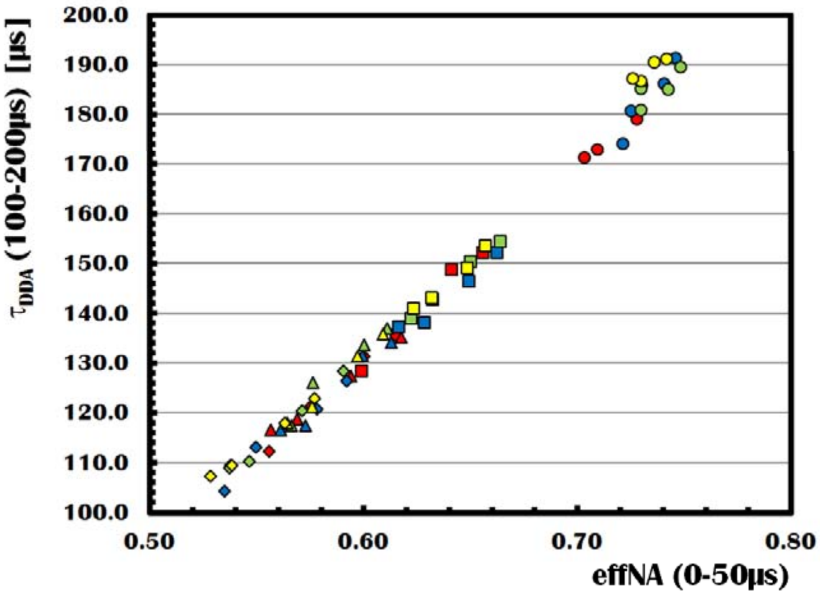
$$\textbf{\textit{effNA}} = \textbf{\textit{DDA}}^{FF} / \textbf{\textit{DDA}}^{SFA}$$

⇒Ratio of DDA signal for fresh fuel (FF) and spent fuel (SFA) for given ***M*** and given time domain



Issues of practicality – *effNA* vs. τ_{DDA}

- correction of DDA signal works best with ***effNA*** from 0-50µs time domain
=> potential problems with electronics so short after the interrogating pulse
- fresh fuel assemblies needed to evaluate ***effNA*** – maybe, not a big issue
- ***BUT (!!)*** – recently found that ***effNA***$_{(0\text{-}50\mu s)}$ ~ τ_{DDA} in 100-200µs time domain



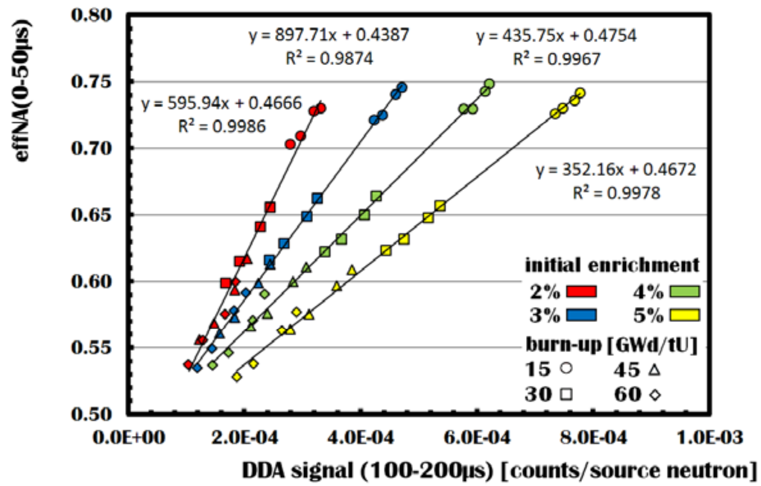
- **τ_{DDA} in 100-200µs time domain is a measure of neutron absorbers**
- what works for ***effNA***, works for τ_{DDA} (*still needs to be quantified*)
- with τ_{DDA} we may avoid problematic time domains too early after the interrogating pulse

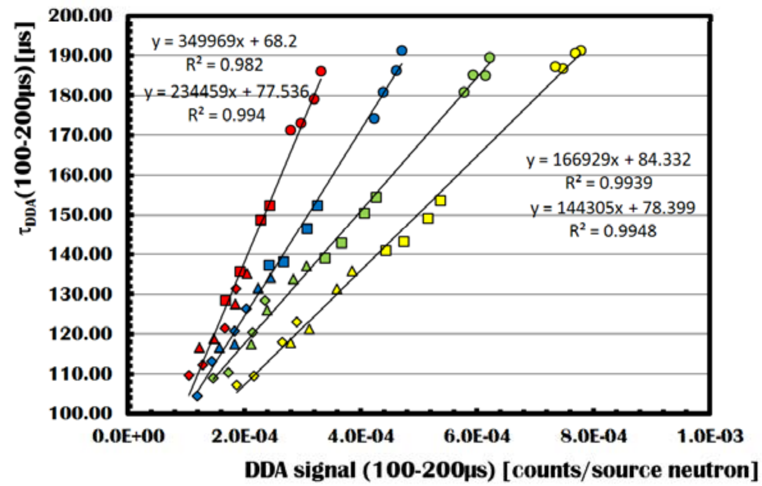
Determination of Initial Enrichment

Two possible approaches:

***Effective neutron absorbers*:**
- comparison to fresh fuel needed
- best time domain 0-50μs

***Die-away time*:**
- time domain 100-200μs
- minor issues with statistics in MCNPX (*should not exist in real life*)





Determination of Initial Enrichment

<u>In general:</u>

$\boldsymbol{effNA} = a_1(IE)\cdot \boldsymbol{DDA}+b_1(IE)$ **OR** $\tau_{DDA} = a_2(IE)\cdot \boldsymbol{DDA}+b_2(IE)$

1) we can consider b_1 and b_2 as constants

2) a_1 and a_2 are linear functions of ***IE*** **…** $a_{1,2} = c_{1,2} \cdot \boldsymbol{IE} + d_{1,2}$

3) then:

$\boldsymbol{effNA} = (c_1\cdot \boldsymbol{IE}+d_1)\cdot \boldsymbol{DDA}+b_1$ **OR** $\tau_{DDA} = (c_2\cdot \boldsymbol{IE}+d_2)\cdot \boldsymbol{DDA}+b_2$

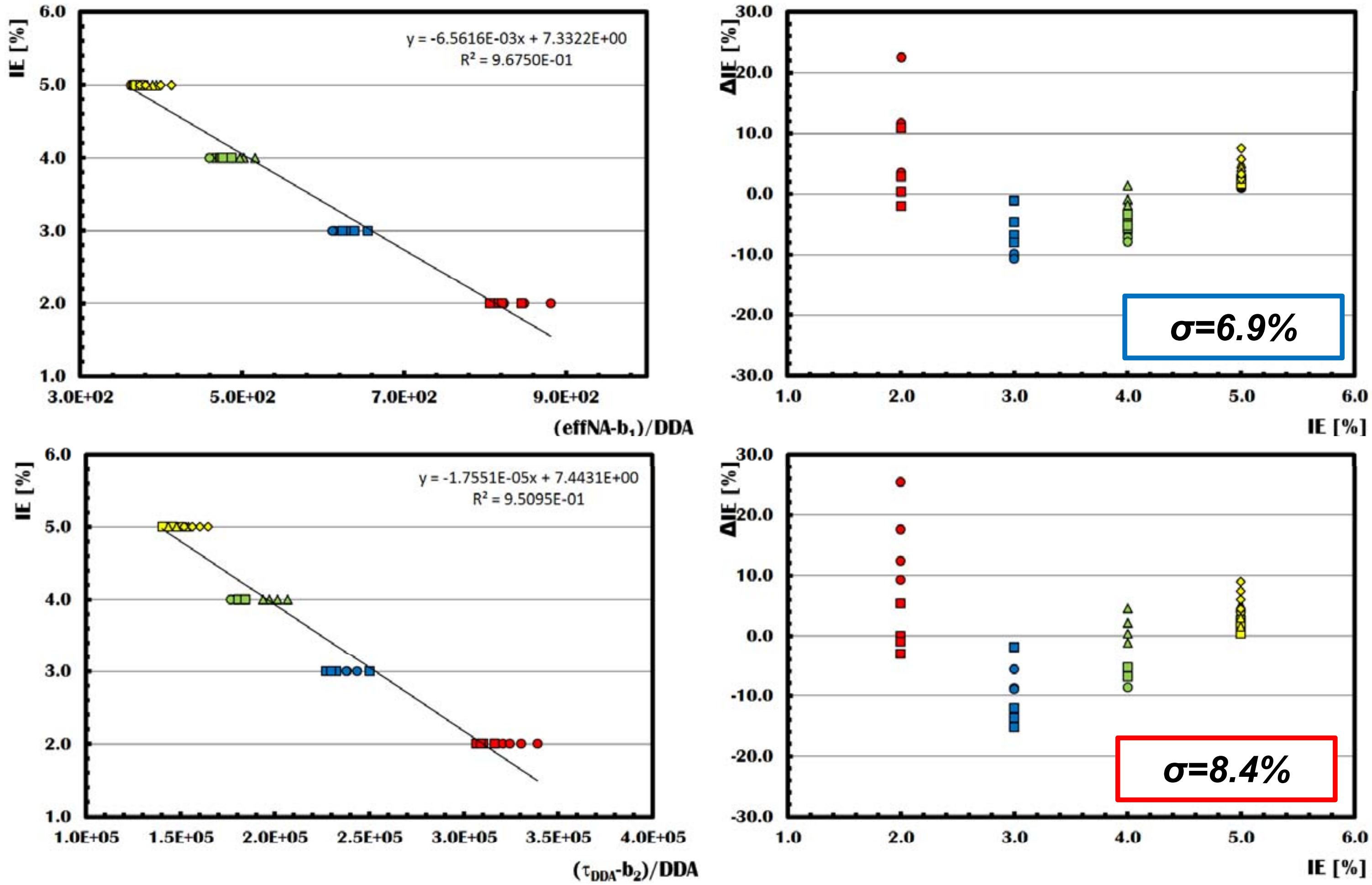
$$IE = \frac{\dfrac{effNA - b_1}{DDA} - d_1}{c_1}$$

$$IE = \frac{\dfrac{\tau_{DDA} - b_2}{DDA} - d_2}{c_2}$$

Determination of Initial Enrichment

effNA method

Die-away time method

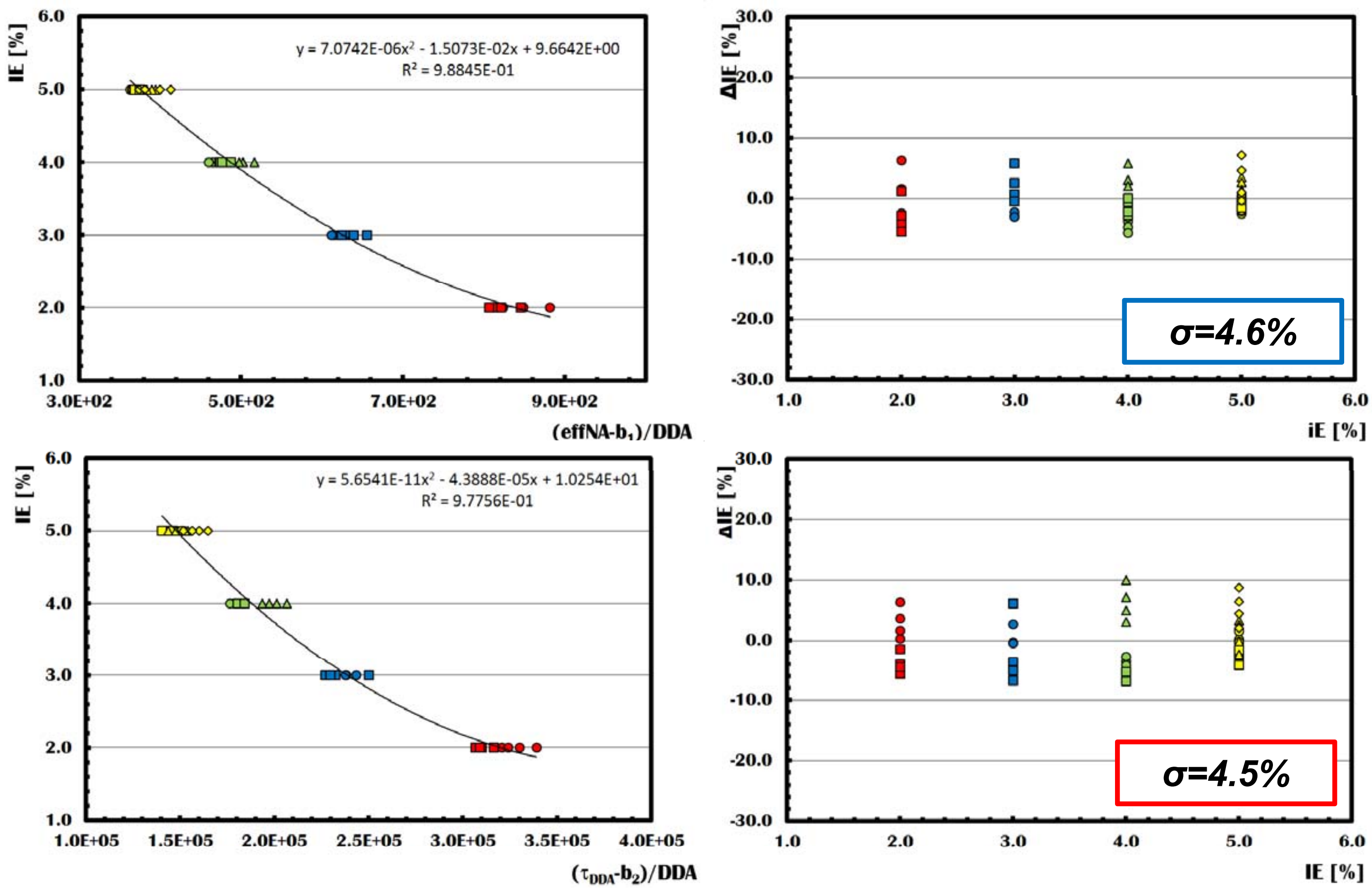


Only realistic SFA's (2% - 15, 30; 3% - 15, 30; 4% - 15, 30, 45; 5% - 15, 30, 45, 60 GWd/tU)

Determination of Initial Enrichment

effNA method

Die-away time method



Only realistic SFA's (2% - 15, 30; 3% - 15, 30; 4% - 15, 30, 45; 5% - 15, 30, 45, 60 GWd/tU)

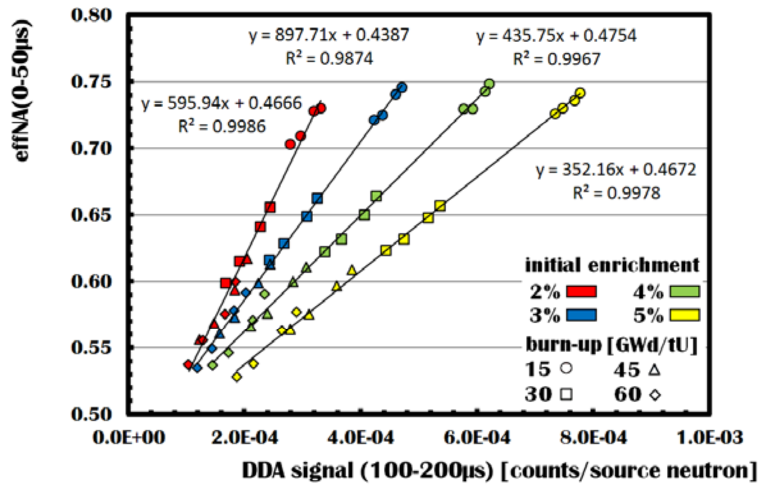
Determination of Burnup

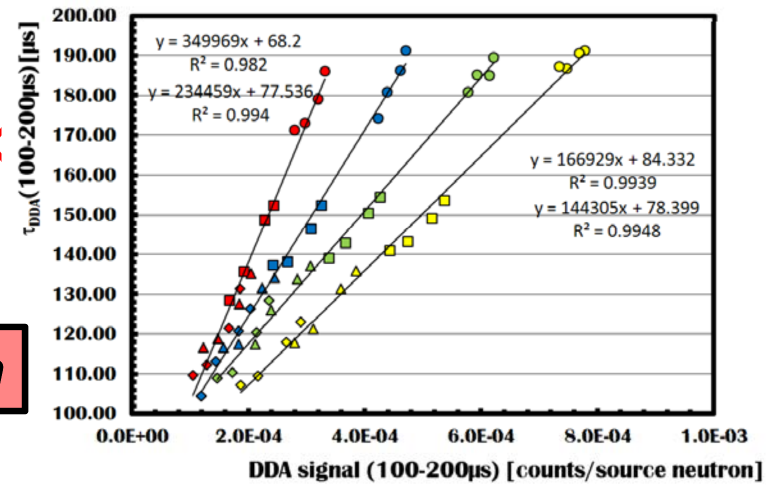
(Again) Two possible approaches:

***Effective neutron absorbers*:**
- comparison to fresh fuel needed
- best time domain 0-50µs

***Die-away time*:**
- time domain 100-200µs
- minor issues with statistics in MCNPX (*should not exist in real life*)

BUT : Cooling time needs to be known





Determination of Burnup

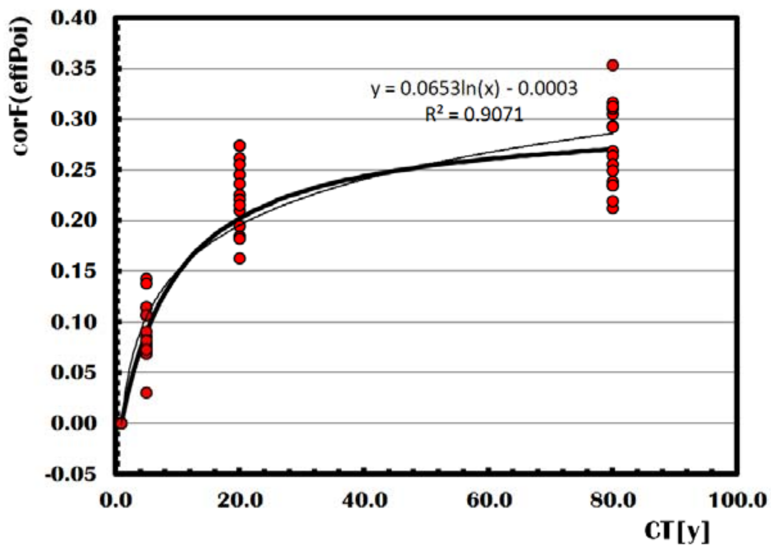
First step:

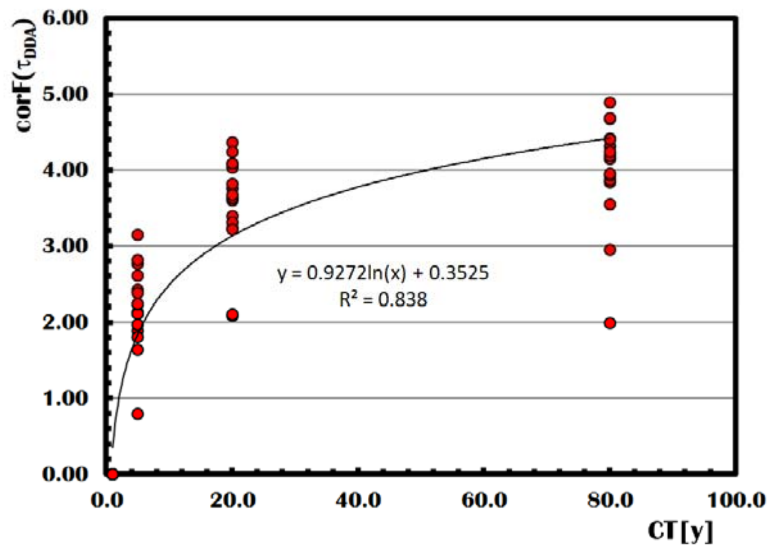
=> correct for cooling time by normalizing to CT=1y (*or any other CT*)

corF(***effNA***) = *f* [***effNA***(CT>1y)-***effNA***(CT=1)] → ***works better !!!***

AND/OR

corF(τ_{DDA}) = *f* [τ_{DDA}(CT>1y)-τ_{DDA} (CT=1)]

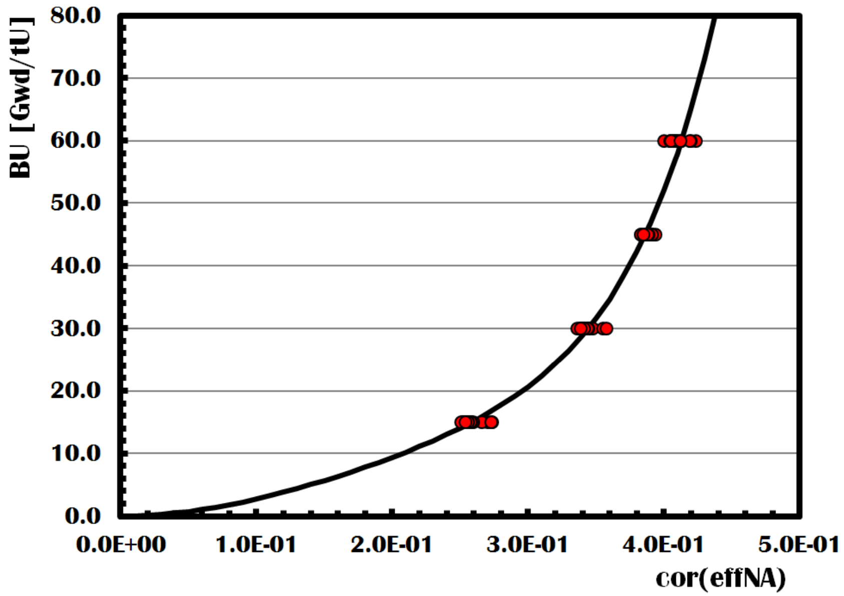


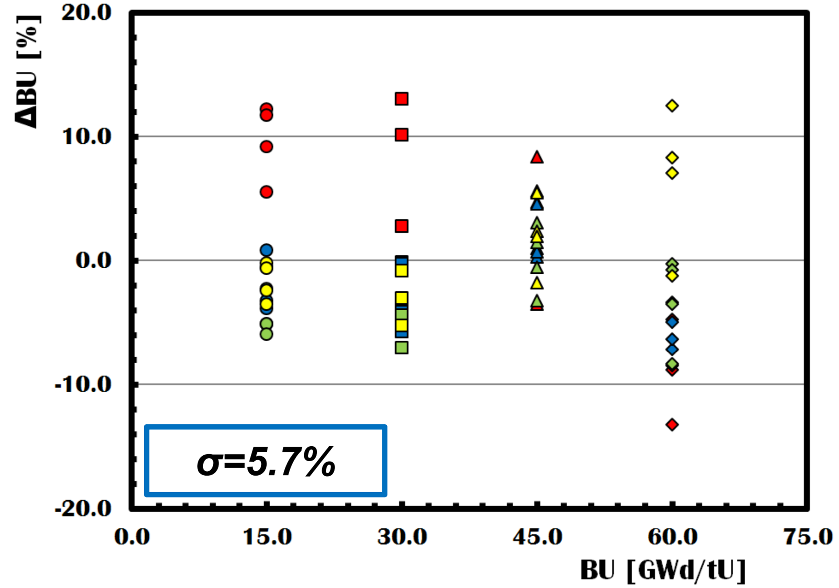


Determination of Burnup

Second step:

=> plot vs. burnup



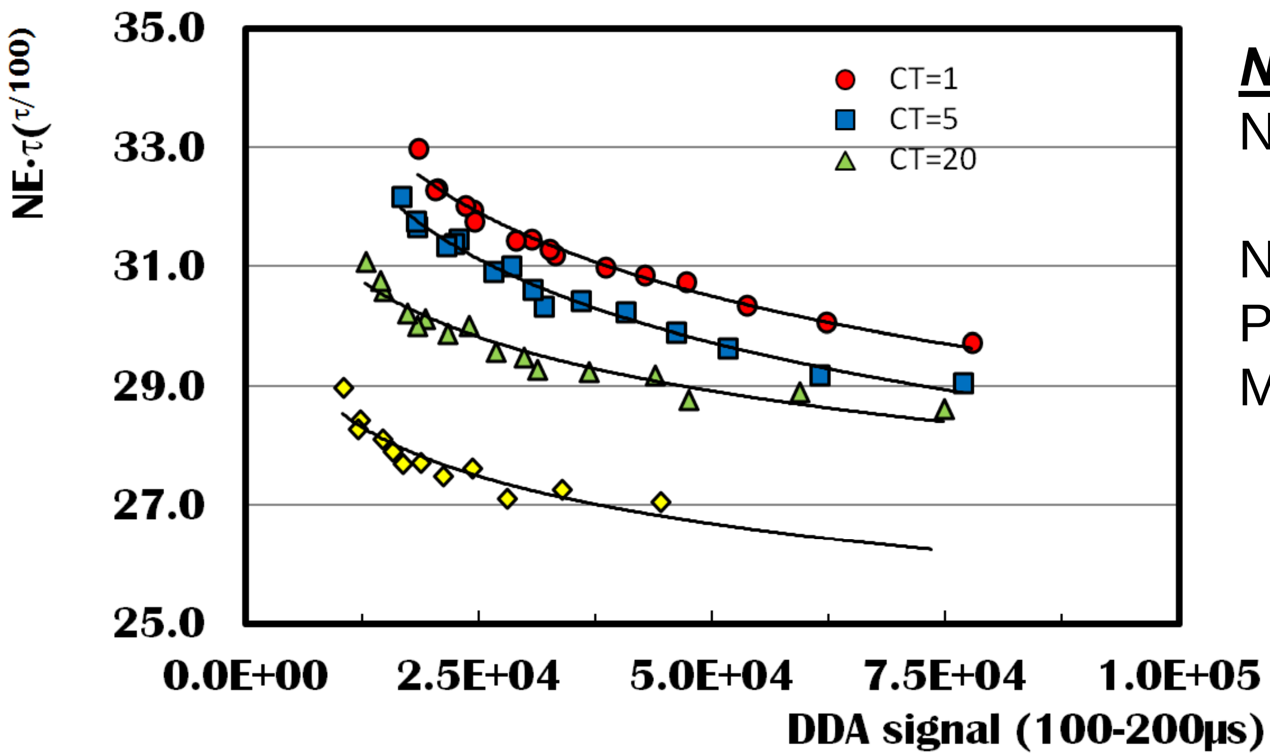


<u>Note:</u> BU determination using die-away time not yet finished, but results are expected to be similar

Determination of Cooling Time

<u>Work in progress</u>

=> first results promising



<u>Note:</u>

NE = PN/M

NE…neutron emission
PN…passive neutron
M…multiplication

Conclusions

❖ **based on SFL-1, DDA instrument can measure/determine initial enrichment (IE) (σ<5%), burn-up (BU) (σ~6%) and cooling time (CT) (σ~20-50%)**

❖ **DDA instrument can also determine ^{tot}Pu (σ<1.5%)** *(see "the other talk")* **and $^{239}Pu_{eff}$ (σ<1.5%)** *(to be published)*

❖ **DDA instrument seem to have a great promise to be able to work as a standalone device, yet integration with other techniques may be still beneficial** *(accuracy, redundancy, diversion detection, etc. …)*