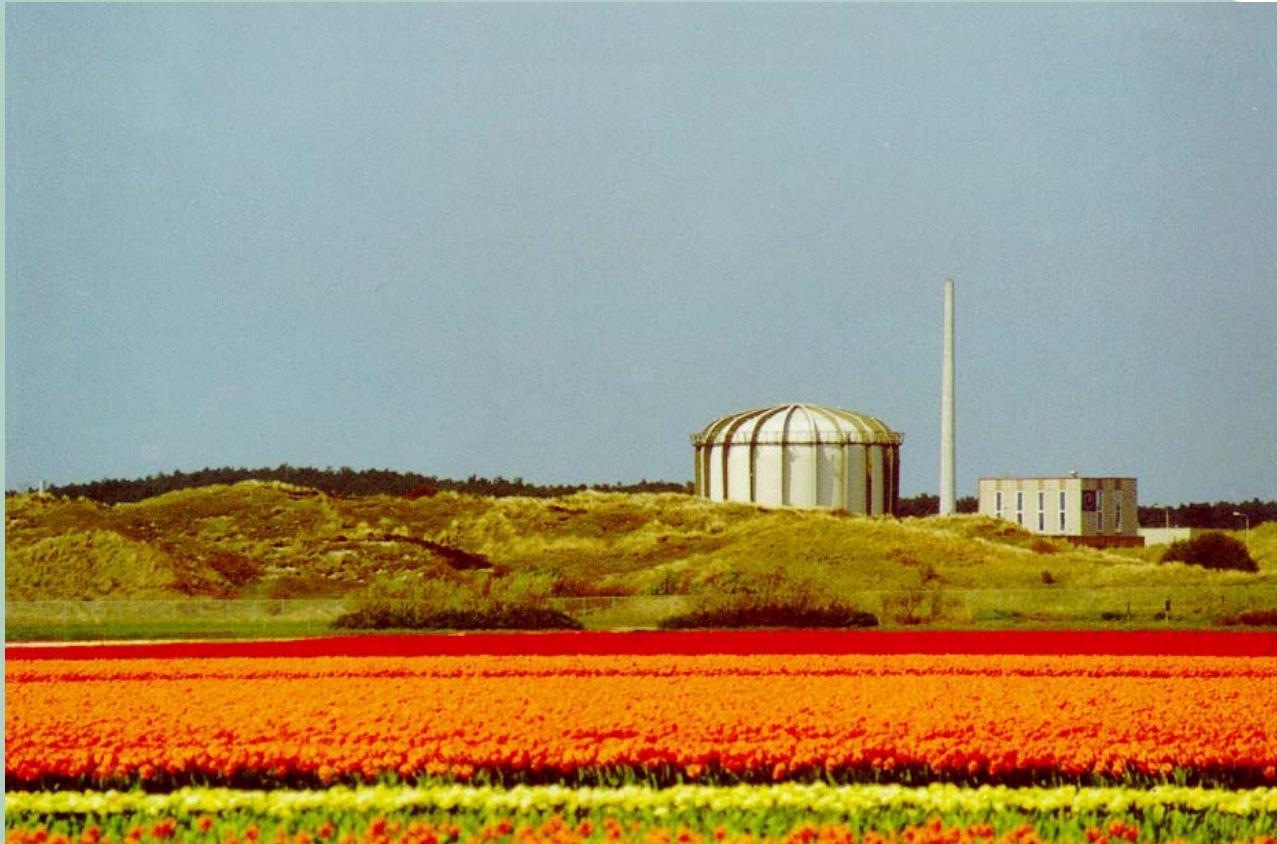


HEU-LEU Conversion of the Petten HFR

Fred J. Wijtsma Reactor Manager HFR/LFR

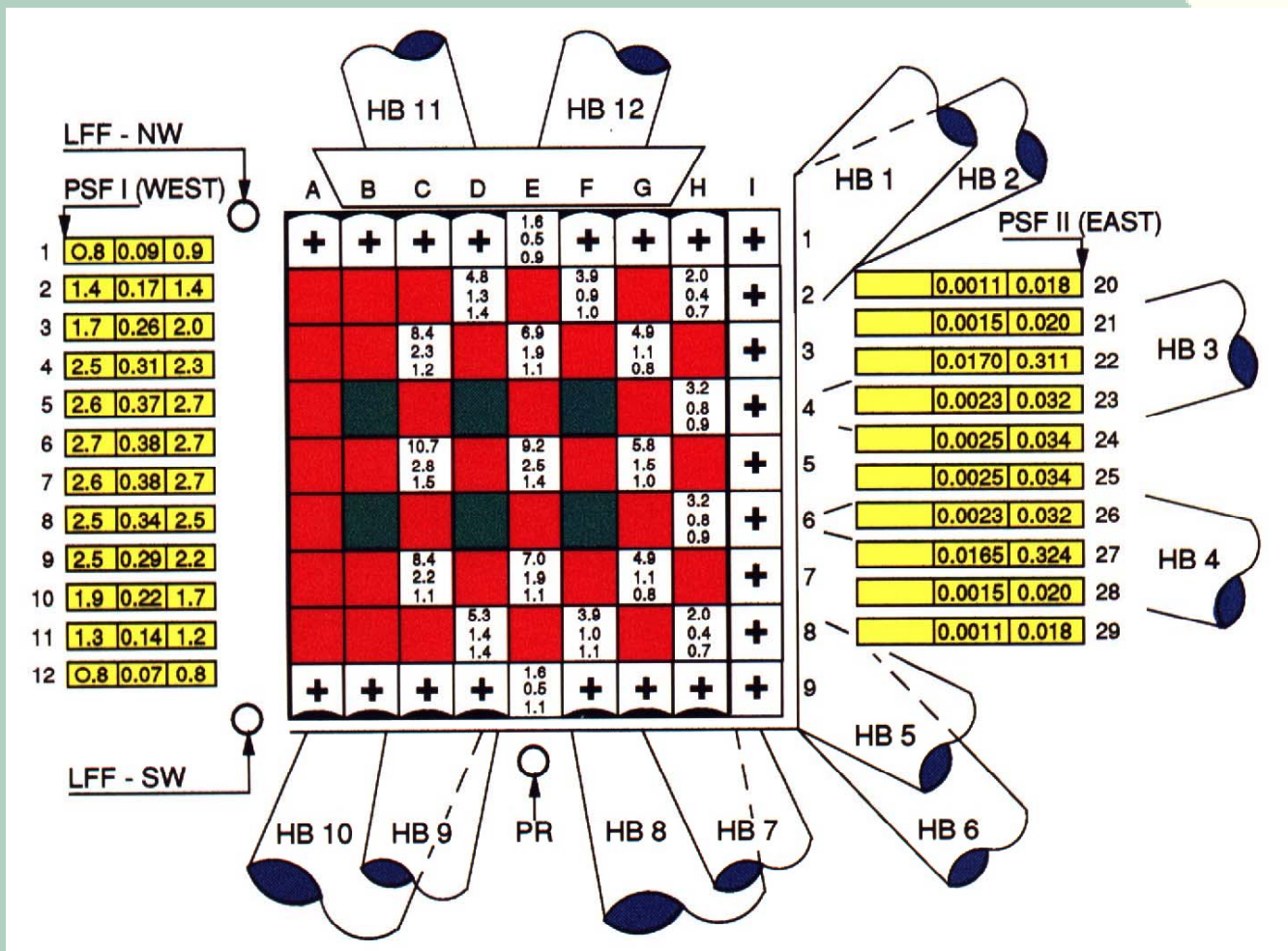


RRFM 30 April – 3 May 2006 Sofia Bulgaria

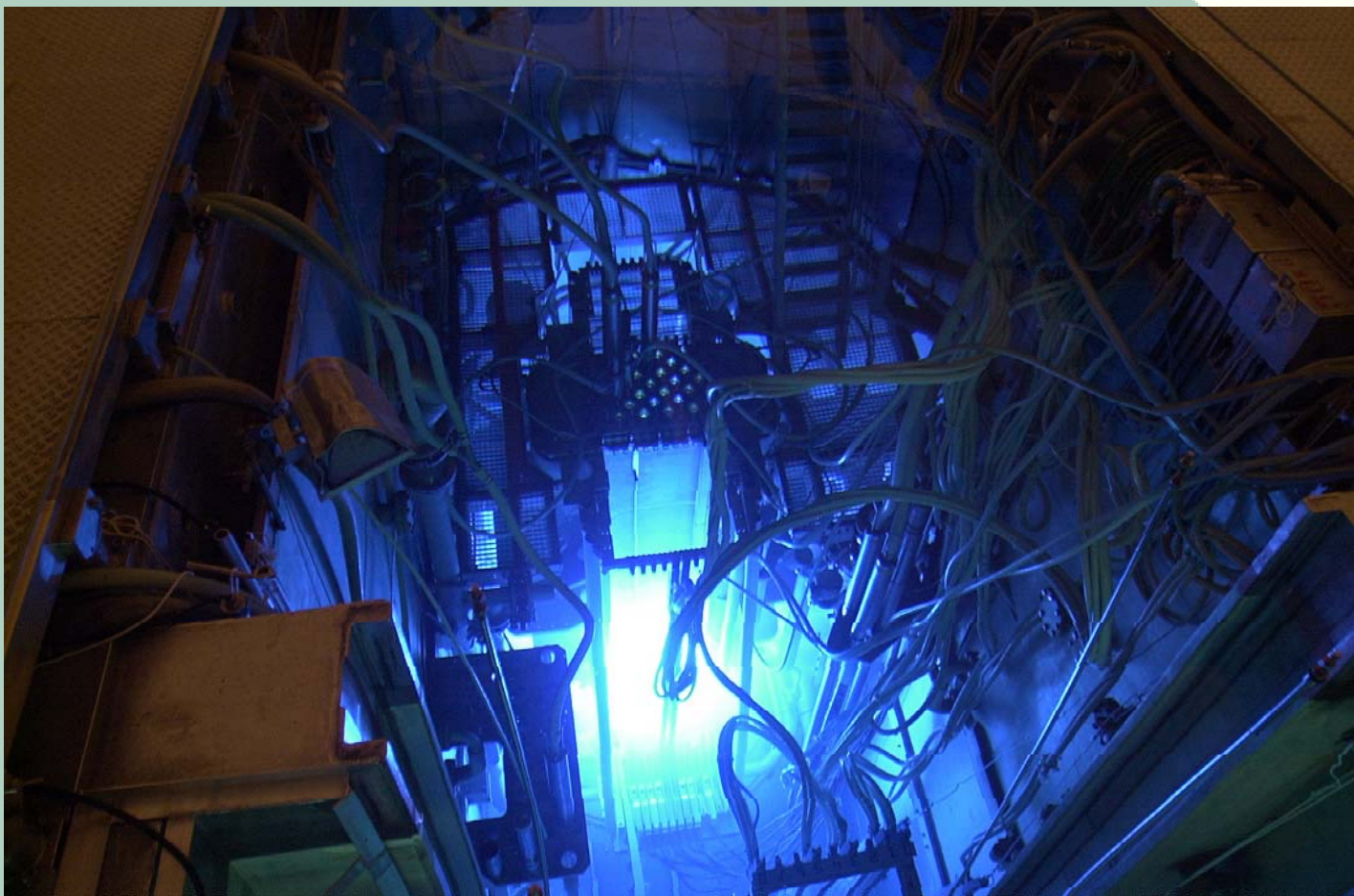
High Flux Reactor

- 50 MW MPR tank in pool
- 17 in-core, 12 PSF and 12 beam positions
- Approximately 300 Full Power Days per year
- Safe and reliable operation within license requirements
- Materials Testing
 - Graphite ageing
 - Steel
 - Fusion
- Isotopes production and Silicon doping
 - Molybdenum, iridium, lutetium

Cross Section of Reactor Core



View in Reactor Pool



RRFM 30 April – 3 May 2006 Sofia Bulgaria

Background HFR Conversion Study

- Fulfil non-proliferation requirements
- Fully qualified and licensed fuel
- US supply of HEU and spent fuel return option
- Optimal element design and core reloading strategy
- Gradual core conversion
- Minimum flux penalties for radioisotope production
- Increased cycle length (28 FPD)
- Close cooperation ANL/JRC/NRG

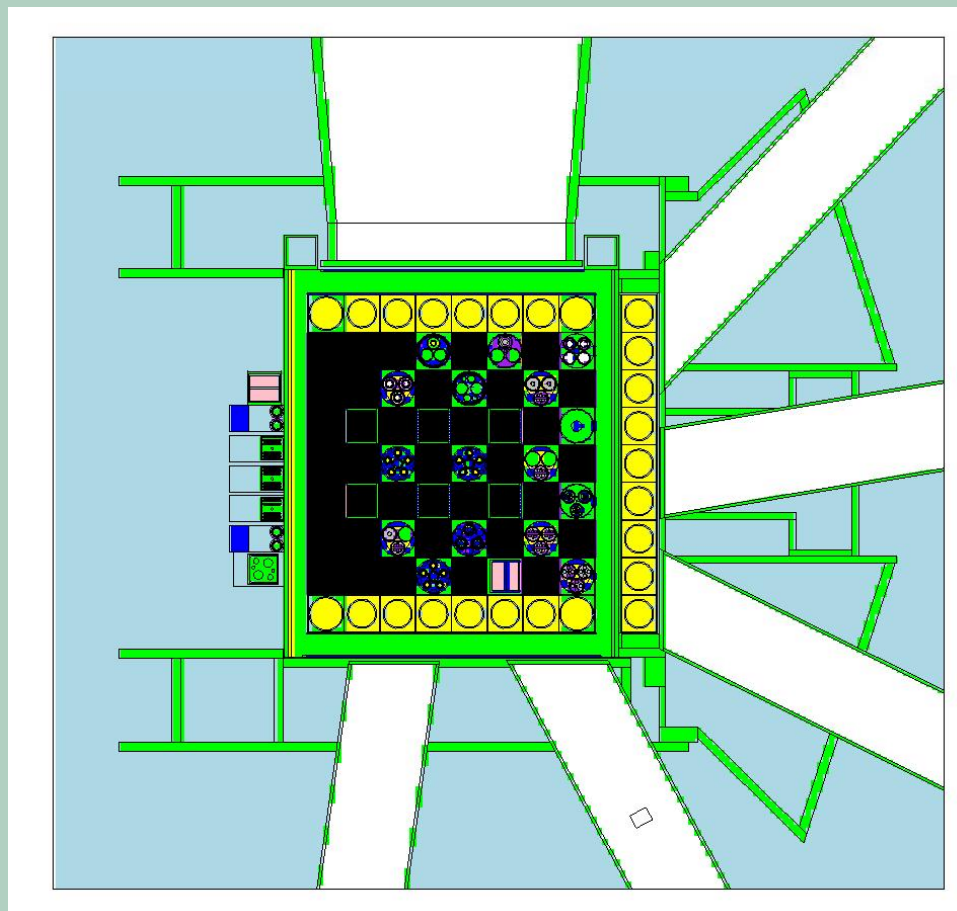
HEU-LEU Conversion History

- 1999: Joint Research Centre took decision to convert;
- 1999: Technical Qualification Program started (in collaboration with ANL);
- August 2005: first LEU elements delivered;
- October 2005: first LEU elements introduced;
- May 2006: conversion completed, first full LEU core in use.

Reactor Core Definitions

- License core to verify license conditions
 - Only AL fillers and inserts
- Reference core for global nuclear calculations
 - Flux traps, absorbers
 - AL-plugs
- Representative Cycle Core (RCC) for detailed nuclear calculations
 - Existing materials, experiments
 - Fuel pin irradiations
 - Radioisotope rigs

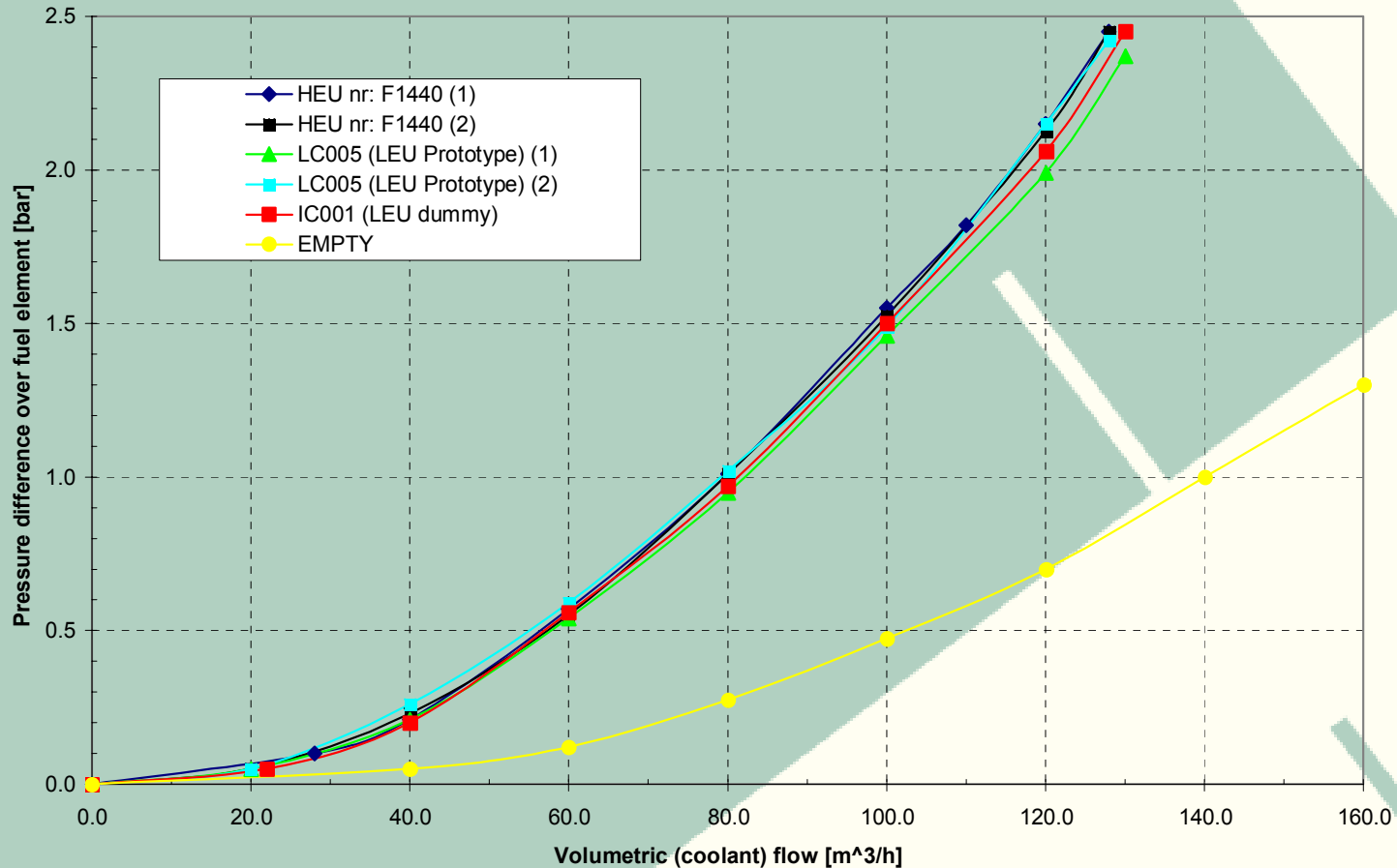
MCNP Model of HFR Core



Technical Qualification of Conversion

- Literature study
- Neutronic calculations
- Hydraulic pressure drop
- Thermal hydraulic analysis
- Finite element analysis/structural analyses
- Core optimisation
- Fuel cycle/ criticality aspects
- Incident/accident calculations
- In-pile testing LEU prototype

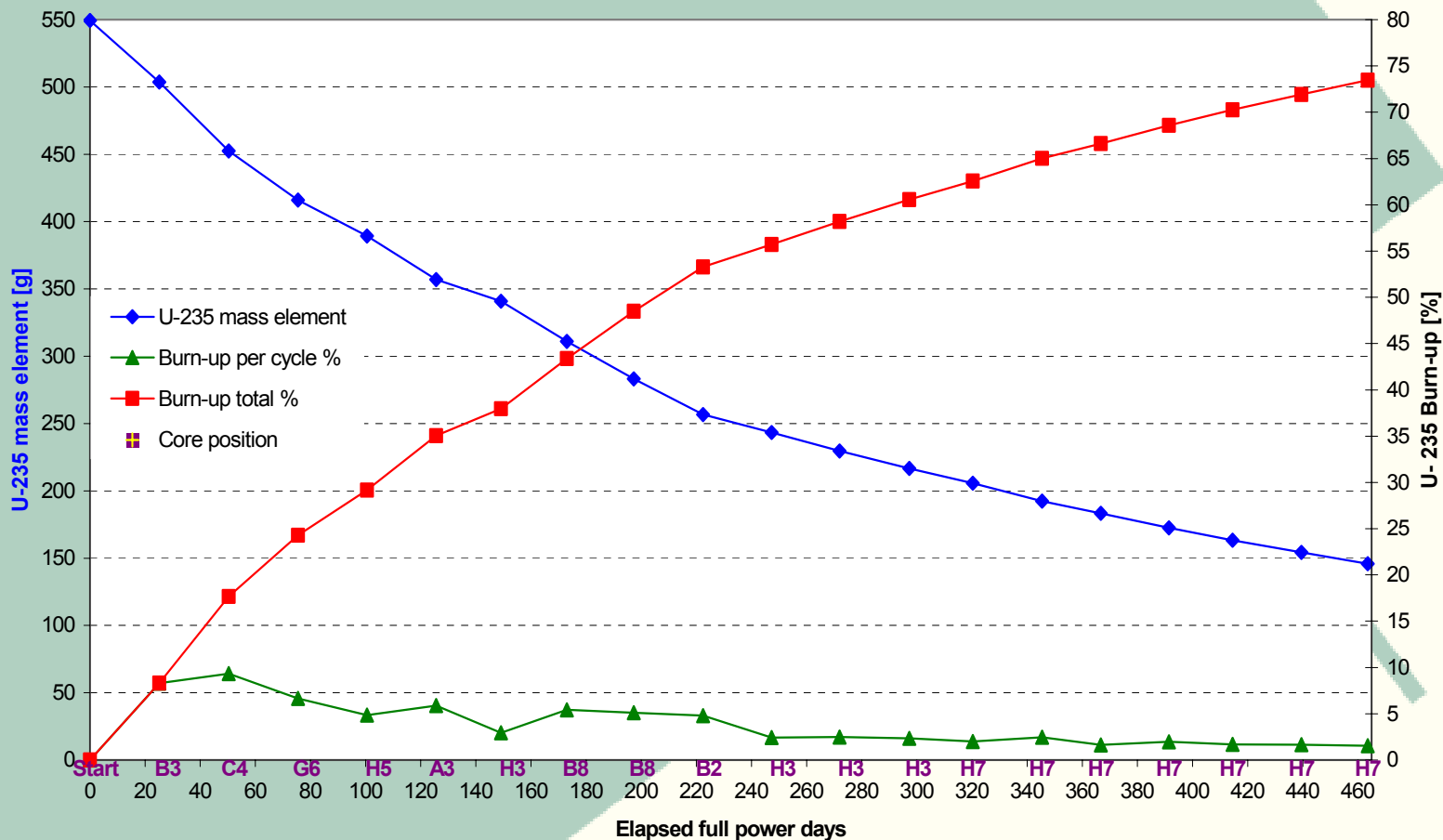
Hydraulic Test Results LC005



HEU-LEU Conversion

- Prototype Testing, 75% Burn-up -

U-235 burn-up PROFEET LEU element LC005 (348-01)



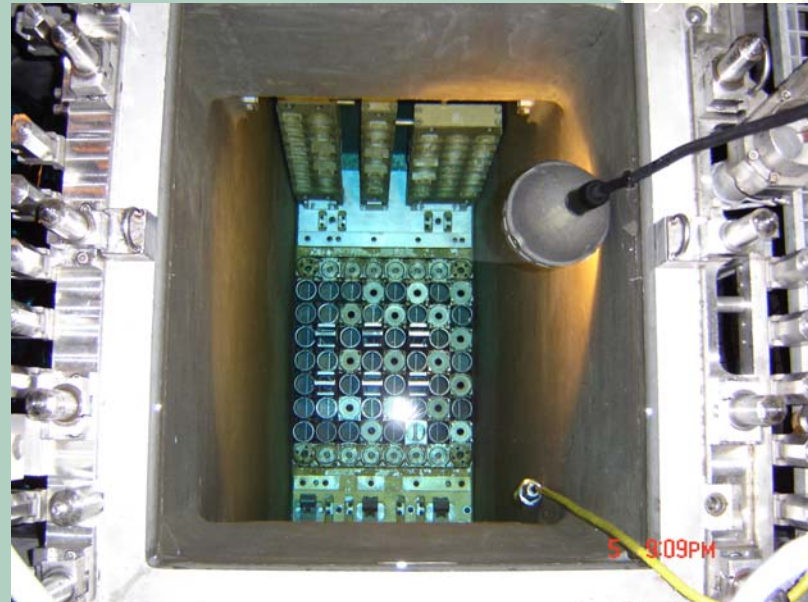
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Core Management

- Fully qualified and licensed fuel
- Progressive Conversion in 7 cycles
- Increase of cycle length (28 > 31 d)
- Minimum loss of thermal flux for isotopes
- Initial loading strategy: business as usual, i.e. “inside-out” fixed reshuffling pattern
- “Optimisation” of loading strategy: change reshuffling pattern into “outside-in”

High Enriched Uranium

- UAl_x in Al matrix
- 93 % enrichment
- 450/310 g ^{235}U in F/CR
- 23/19 fuel plates in F/CR
- ^{10}B slab burnable poison
- 50 (45) MW_{th} power



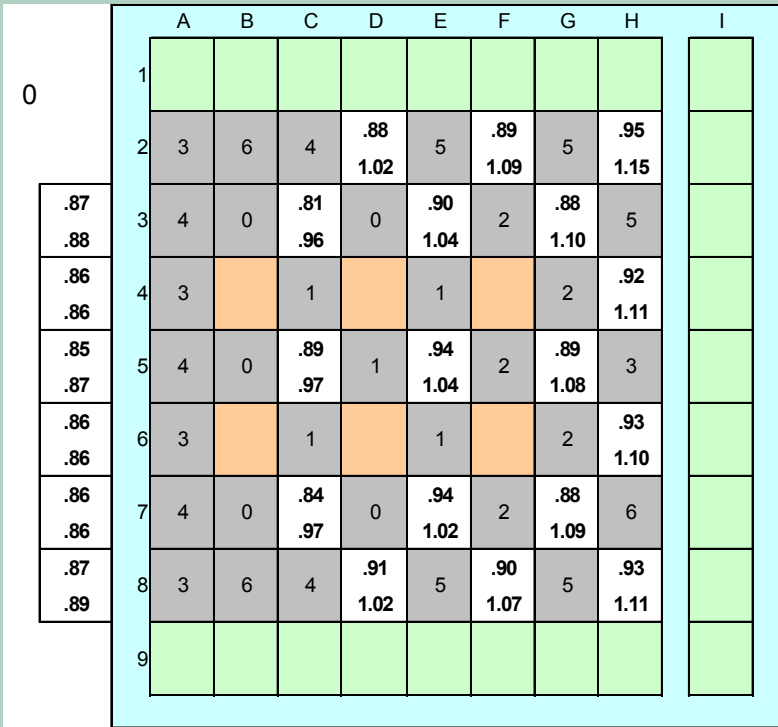
Low Enriched Uranium

- U_3Si_2 in Al matrix
- 19 % enrichment
- 550/440 g ^{235}U in F/CR
- 20/17 fuel plates in F/CR
- ^{113}Cd wires burnable poison
- 50 (45) MW_{th} power

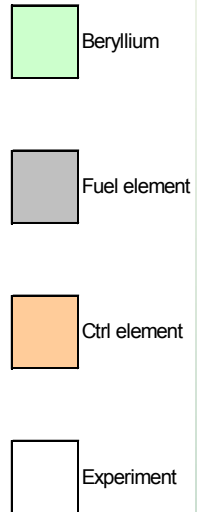
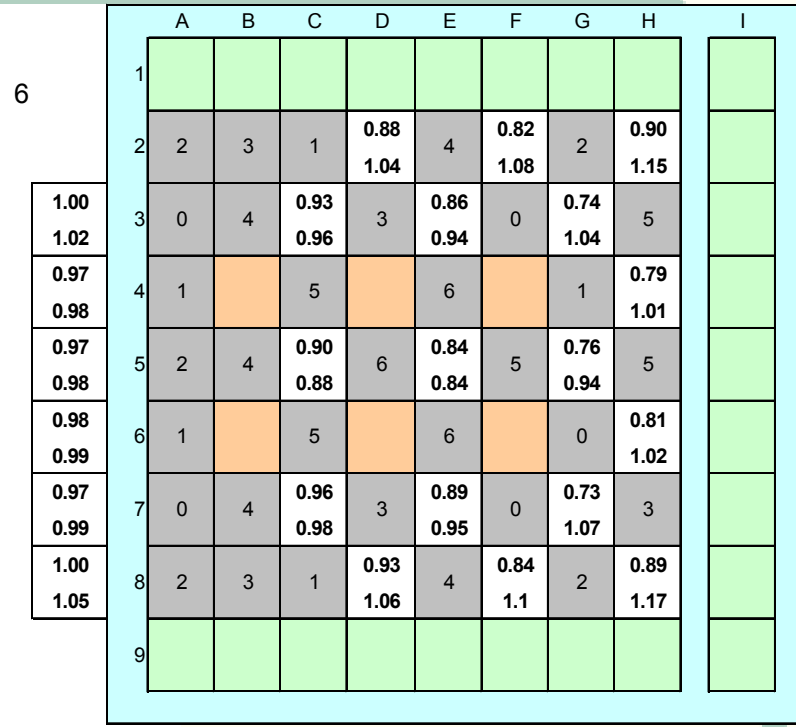


Optimisation of reloading pattern

HEU inside->out



LEU outside-> in



Average thermal flux ratios:

PSF	Core	North	0.890
0.862	0.899	South	0.904

Average thermal flux ratios:

PSF	Core	North	0.831
0.982	0.845	South	0.864

Nc= 484

LEU operational License

- Set of Design Requirements:
 - Thermal hydraulic criteria (3);
 - Reactivity criteria (5);
 - Burn-up criterion;
 - Operational criteria (2);
 - Transient criterion.

Computational Tools

- Reactorphysics codes:
 - REBUS (3D diffusion)
 - o Fuel depletion calculation;
 - MCNP (Monte-Carlo)
 - o Neutron fluence rates and spectrum;
 - o Reaction rates (for validation purposes);
 - o Core reactivity;
 - o Radiation heating.

Computational Tools (cont.)

- Reactorphysics codes (continued):
 - OSCAR-3 (3D nodal)
 - o Fuel depletion calculation;
 - o 7-Group neutron fluence rates and spectrum;
 - o Reaction rates (for verification purposes);
 - o Core reactivity.

Computational Tools (cont.)

	REBUS/MCNP	OSCAR
Computer runtime	days	minutes
Detail	High	Low
QA/QC	Validated	Verified
Use	Complex Experiment design	Support of fuel management

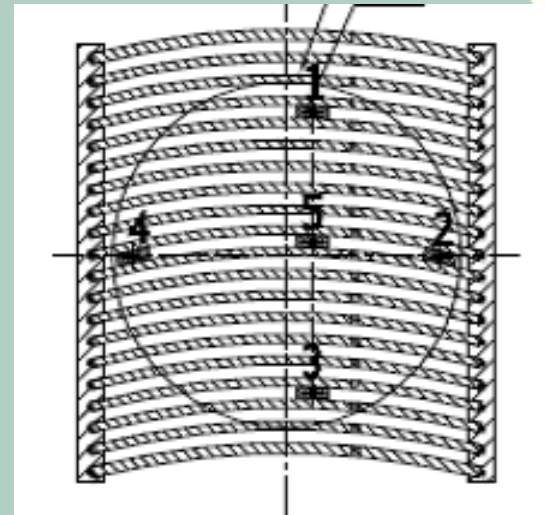
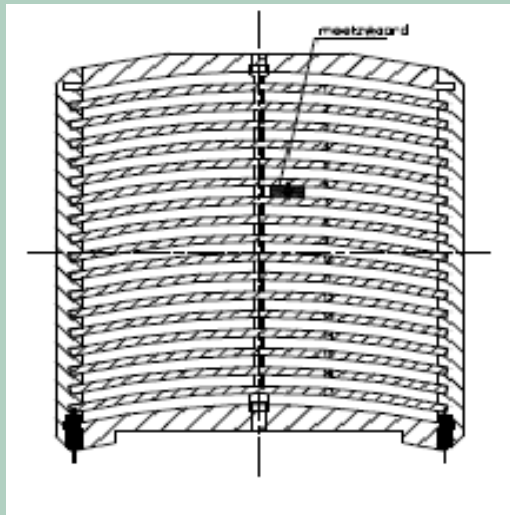
Computational Tools (cont.)

- Custom made:
 - Thermal hydraulics module (bubble detachment);
 - ElNinjo (automated MCNP to OSCAR model generator, including scatter matrix);
 - Post-processor for OSCAR results (DPA's).

Validation of REBUS/MCNP

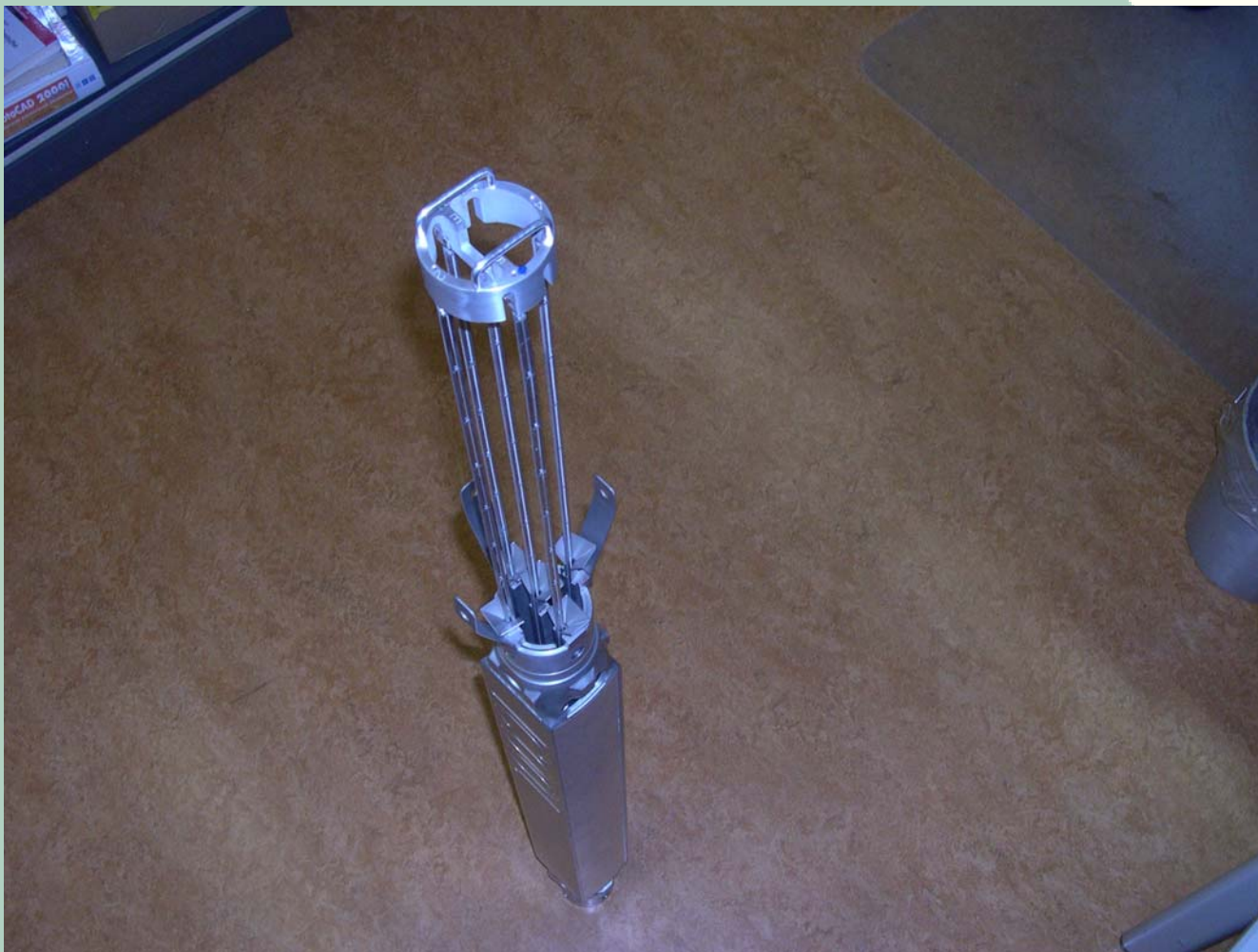
- Copper wire measurements
- Control rod data
- Activation foils measurements

Wire activation measurement in the HEU-LEU mixed cores



- Cycles 2005-10, 2005-12, 2006-03
- LEU wire positions in LEU
- HEU wire position in HEU

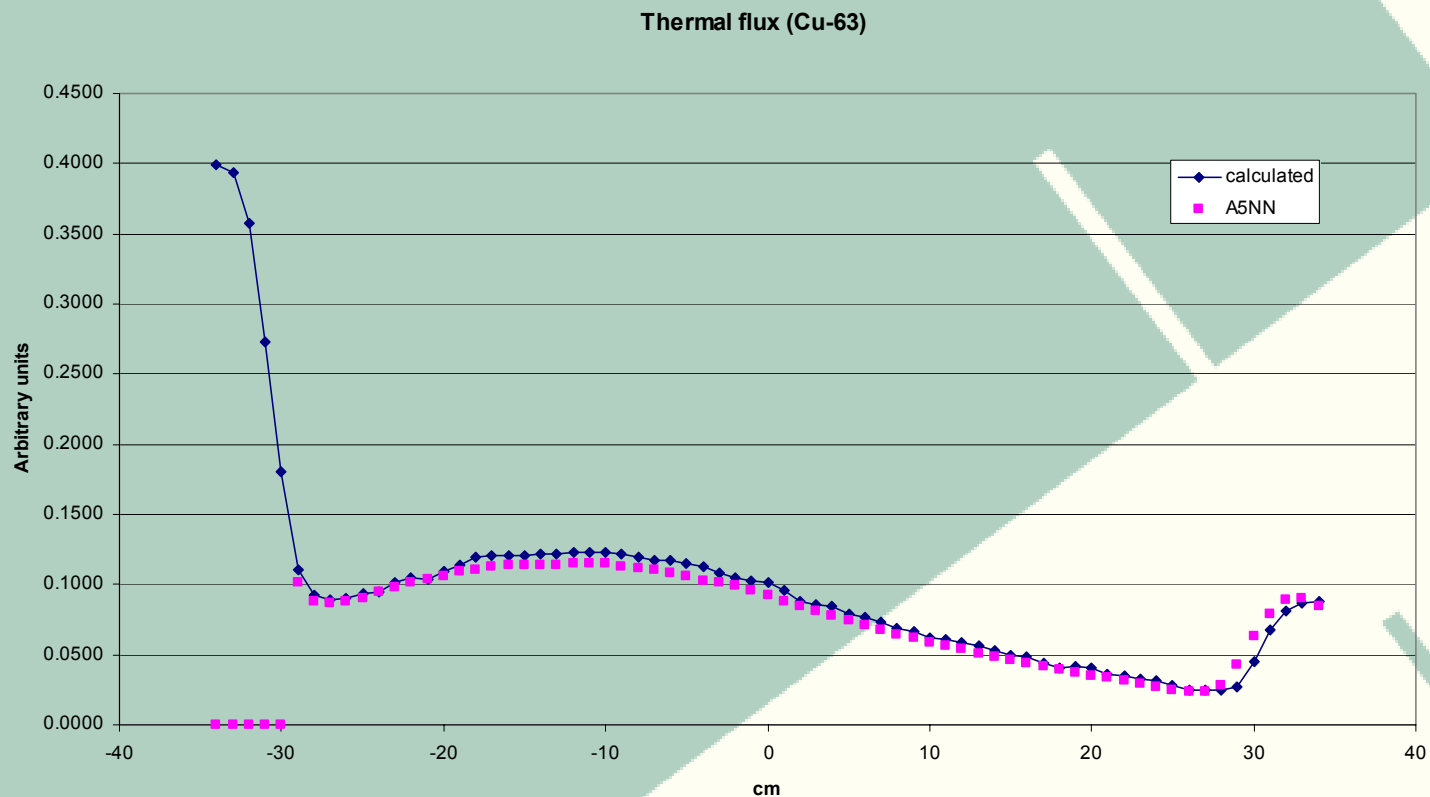
Loading of Flux Wires



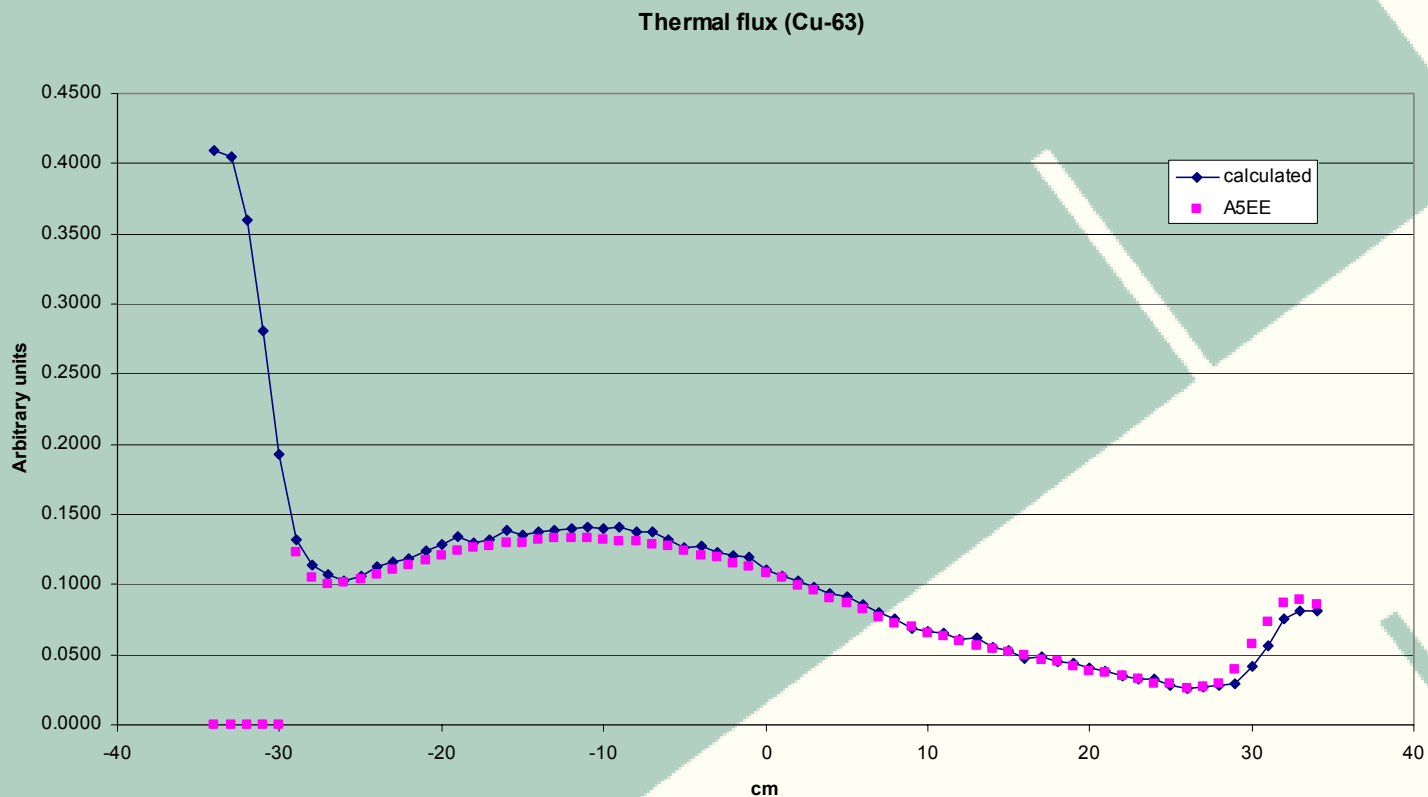
Loading of Flux Wires (cont.)



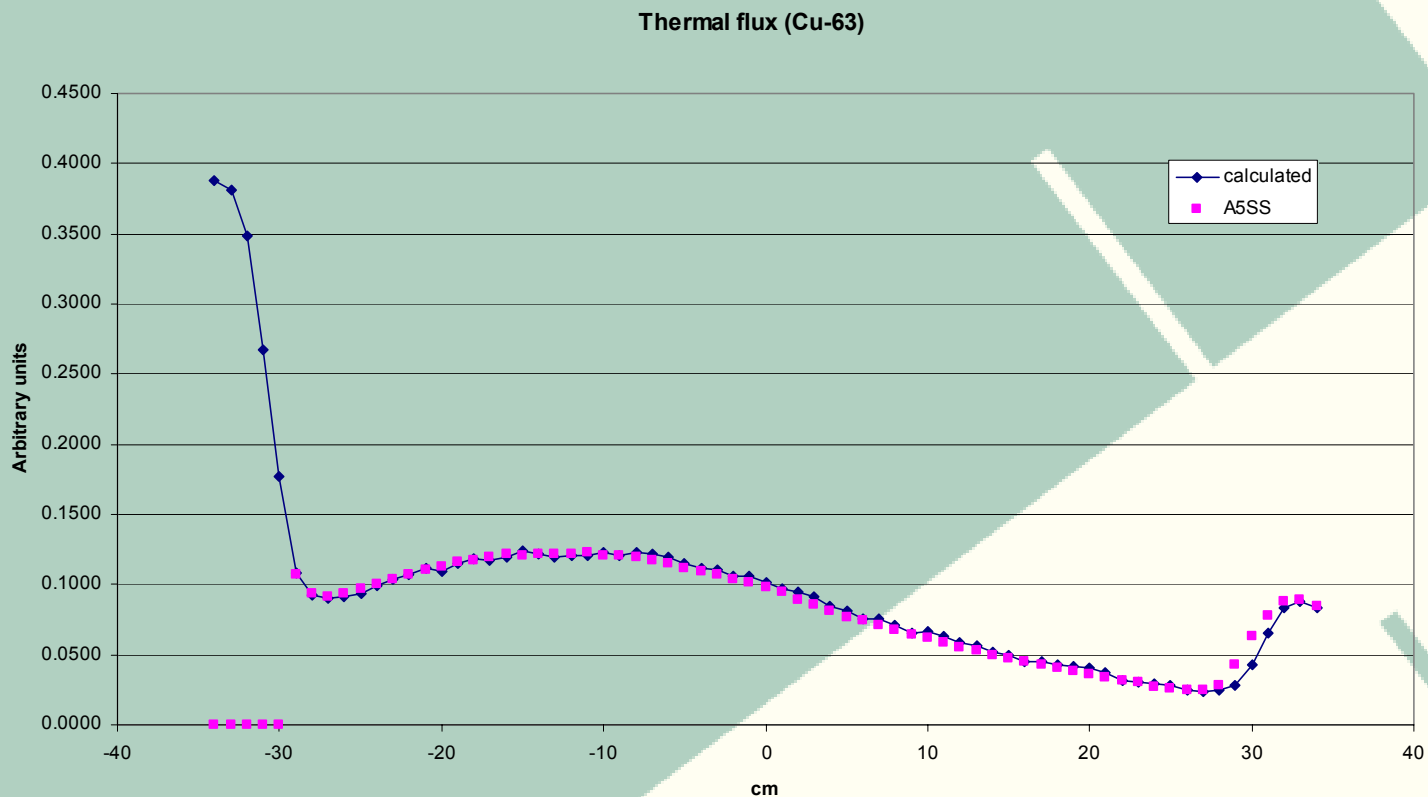
Cycle 2006-03 LEU-A5-North



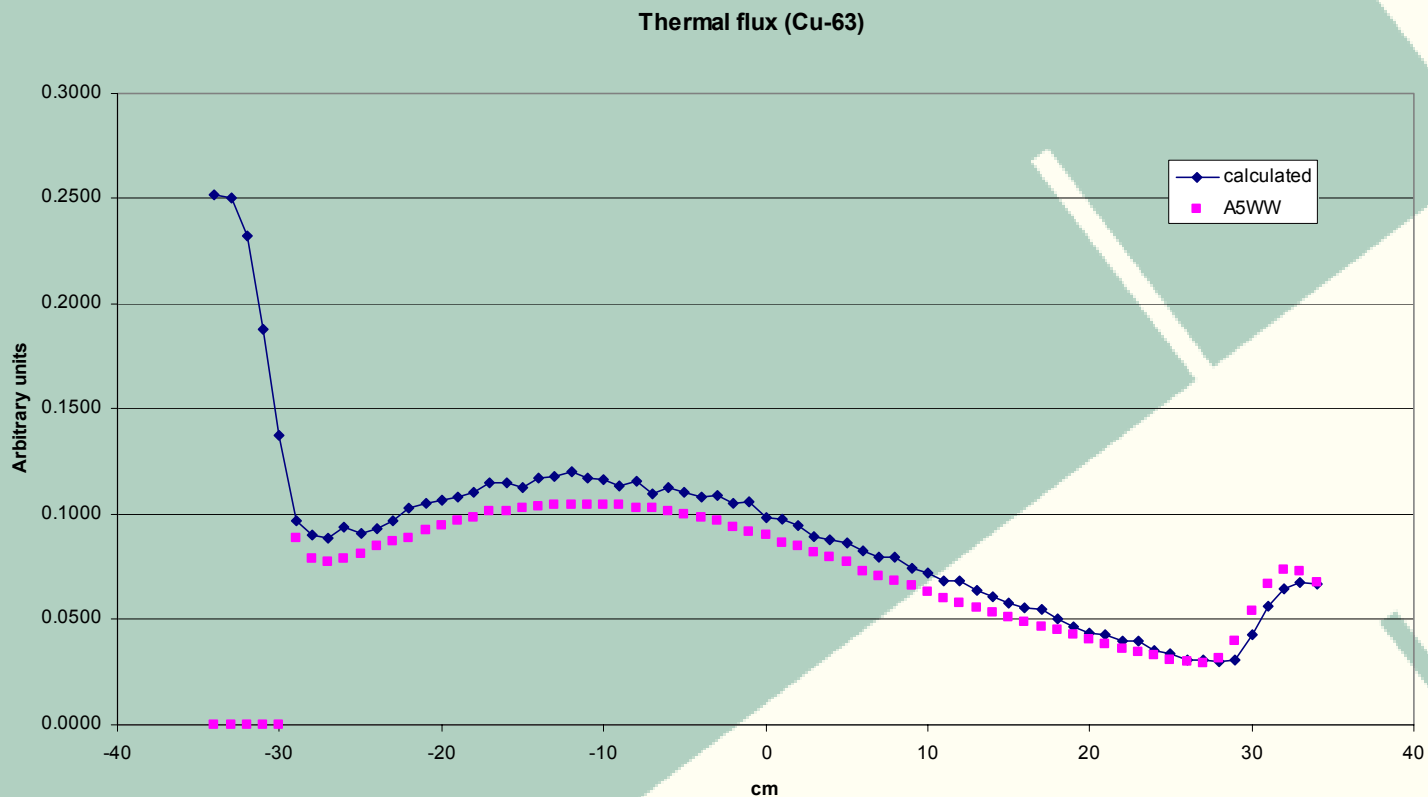
Cycle 2006-03 LEU-A5-East



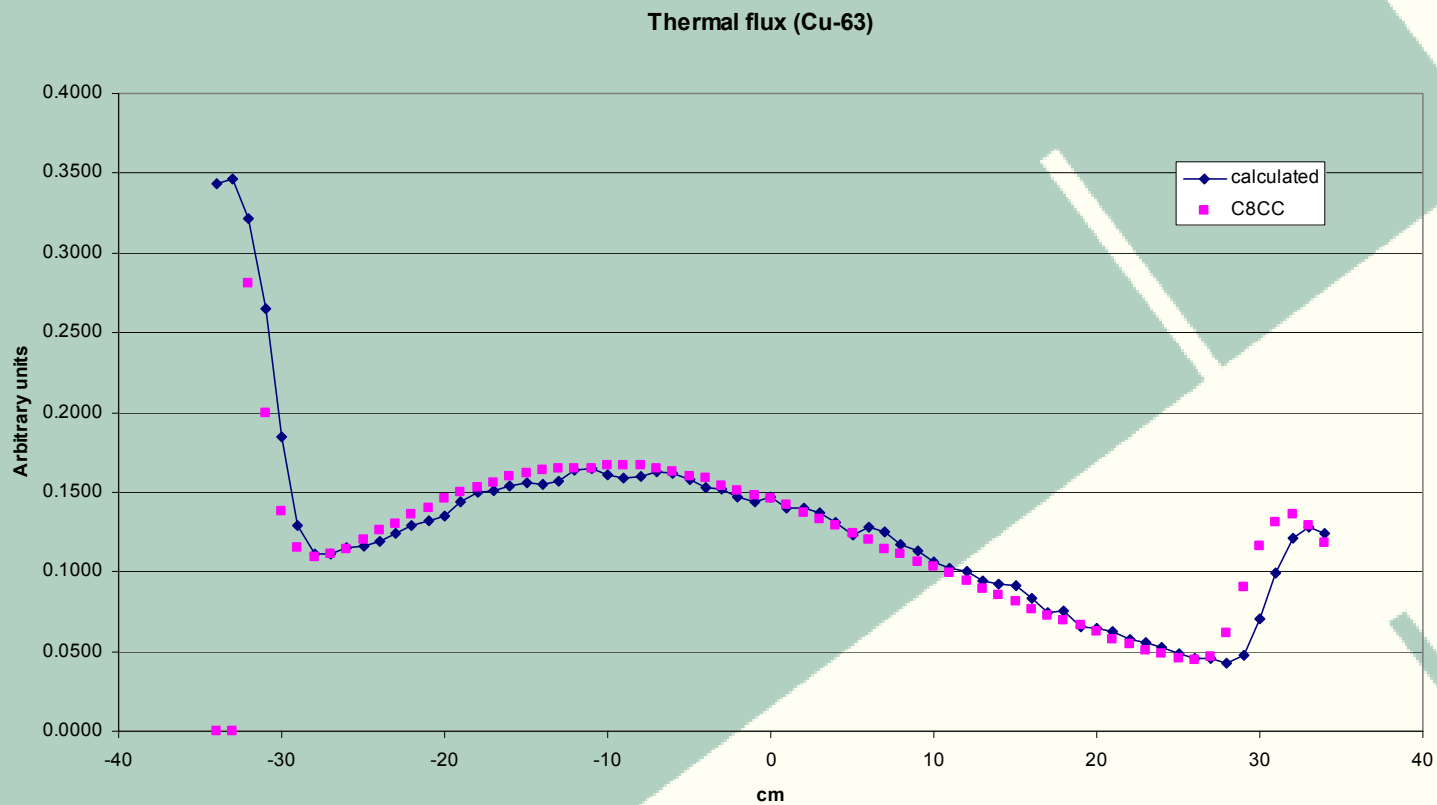
Cycle 2006-03 LEU-A5-South



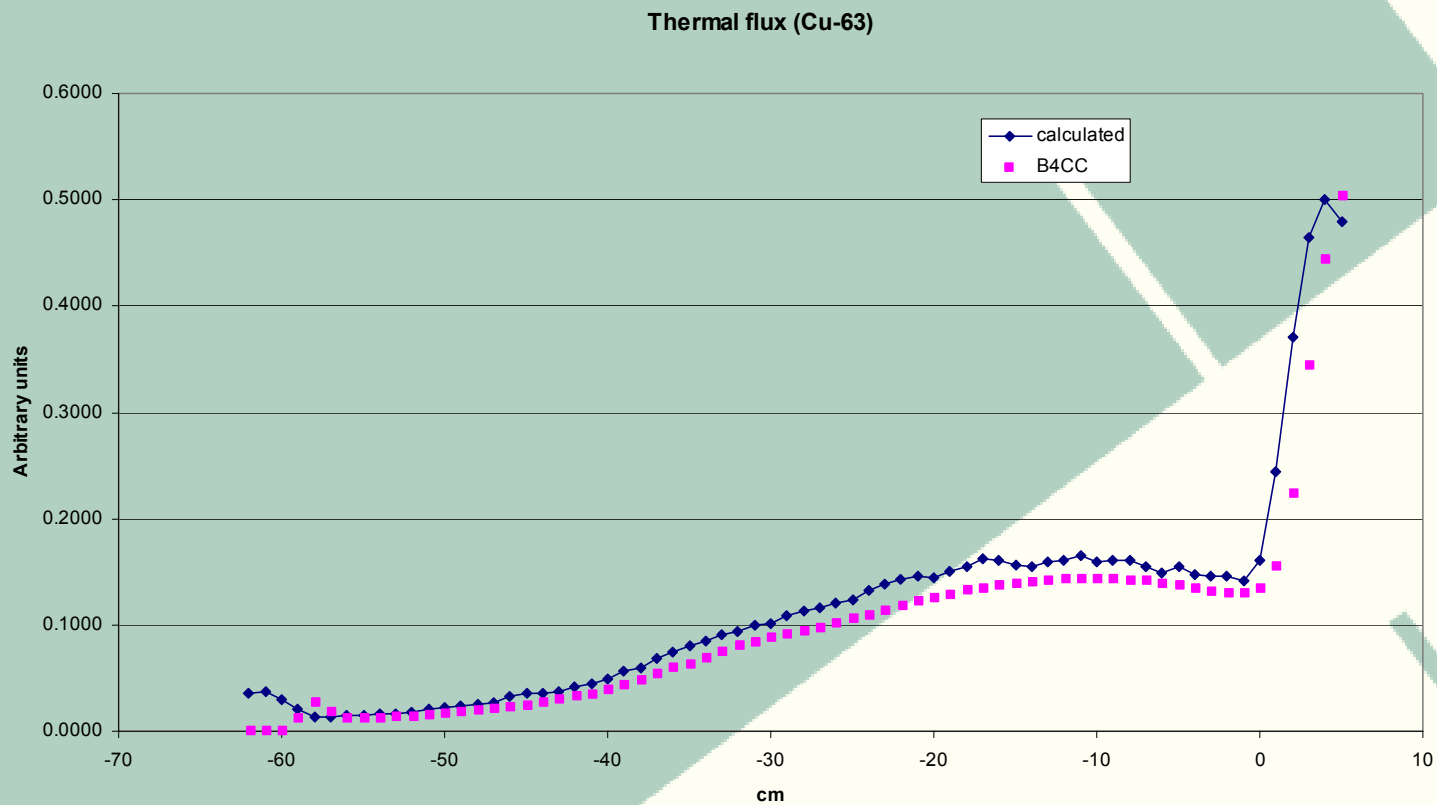
Cycle 2006-03 LEU-A5-West



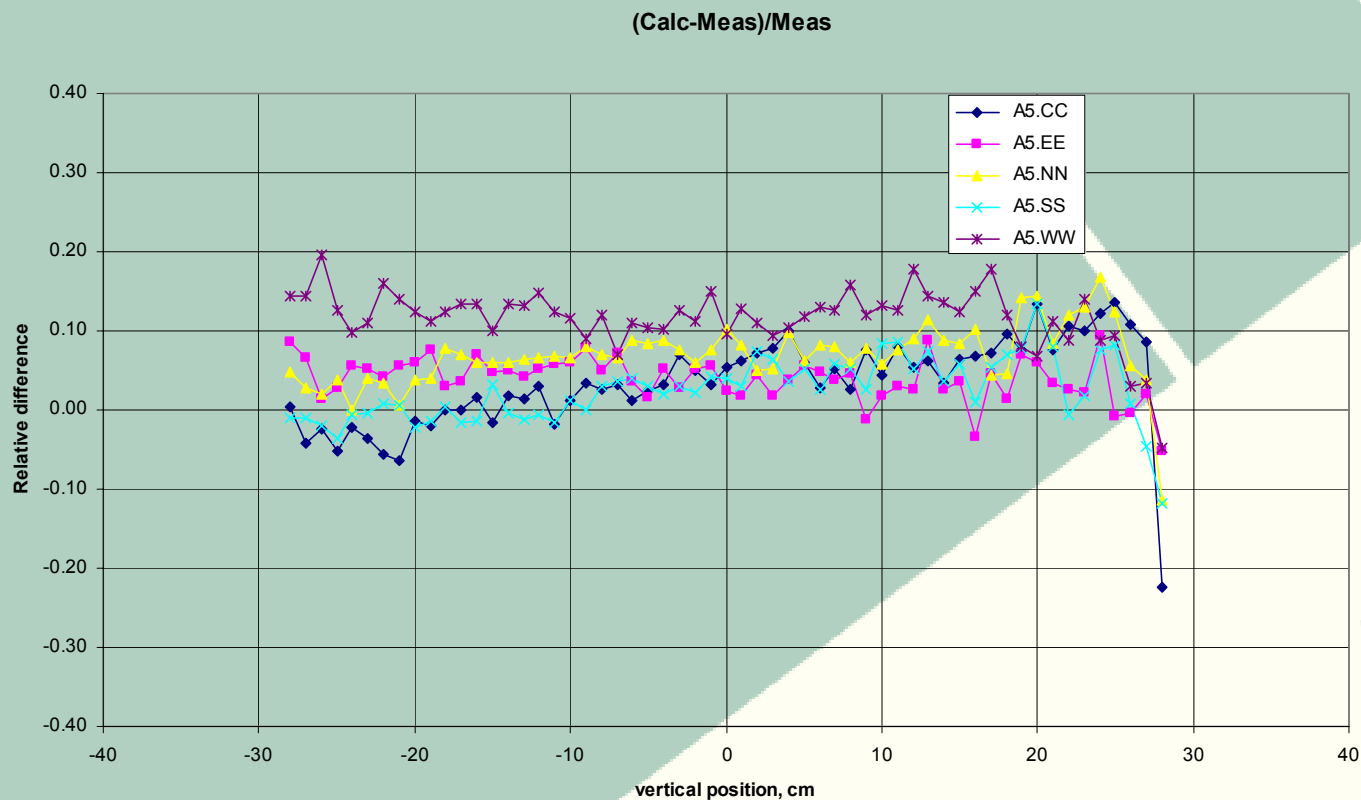
Cycle 2006-03 HEU-B8-Central



Cycle 2006-03 LEU-Control rod B4

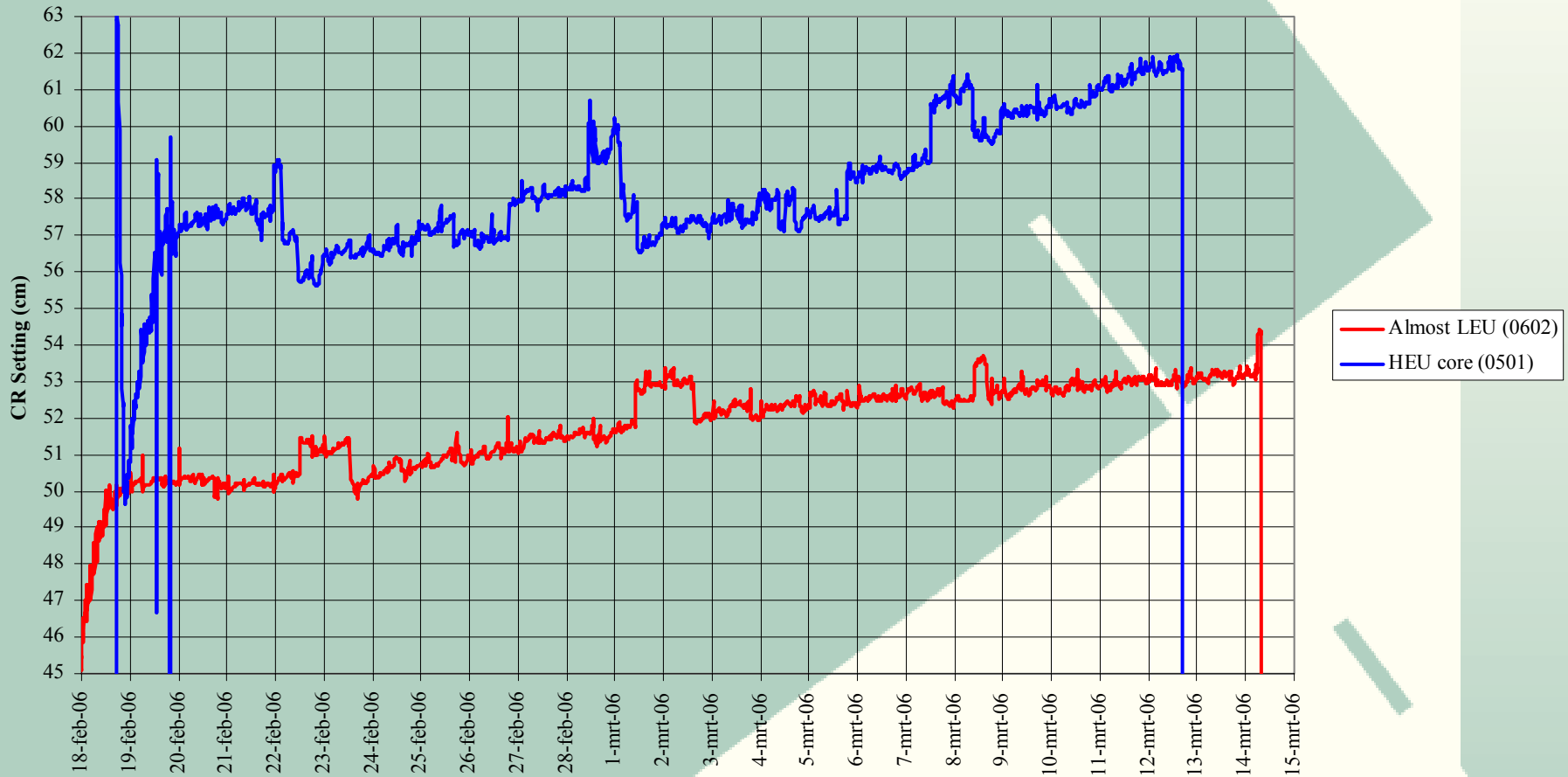


Cycle 2006-03 relative diff. LEU- A5



Reactivity improvement

Comparison HEU and LEU cycle



Activation reactions in metrology sets

- $^{59}\text{Co}(n,\gamma)^{60}\text{Co}$ Thermal
- $^{58}\text{Ni}(n,p)^{58}\text{Co}$ Fast
- $^{54}\text{Fe}(n,p)^{54}\text{Mn}$ Fast
- $^{58}\text{Fe}(n,\gamma)^{59}\text{Fe}$ Thermal
- $^{109}\text{Ag}(n,\gamma)^{110\text{m}}\text{Ag}$ Thermal-epithermal

Reaction rate (-> Flux) absolute values at
45 MW reactor power

Activation analyses of RI-rig

(Calc-Meas)/Meas				
c0510	c0511	c0512	c0601	c0602
G5		G5	G5	E7
0,00		0,01	-0,01	-0,05
-0,02		-0,02	0,00	-0,06
0,03		0,02	0,02	-0,01
0,01		0,03	-0,01	-0,05
0,02		0,03	0,01	-0,02
	D8	D8	D8	D8
	-0,05	-0,04	-0,04	-0,03
	-0,04	-0,08	-0,03	-0,05
	0,00	-0,05	0,01	-0,01
	-0,05	-0,04	-0,04	-0,03
	0,00	-0,01	0,03	0,01

Changes in HFR characteristics

- Neutron spectrum is “harder”:
 - Fast neutron fluence rate is higher;
 - Thermal neutron fluence rate is lower.
- Nuclear heating is lower (in experiments):
 - Heat source is lower, change in thermal behaviour;
- Reactivity has improved; swing has reduced dramatically due to the use of Cd wires as burnable poison in fuel elements.

Conclusions

- The HFR has successfully been converted to LEU fuel;
- The outstanding properties of the HFR have been maintained;
- Both code systems REBUS/MCNP and OSCAR-3 perform well in their specific application.

Acknowledgements

The following persons have made a major contribution to the successful conversion:

- **Argonne National Lab:** Messrs. Matos, Deen, Hanan, Travelli, Hofman;
- **NECSA:** Messrs. Reitsma, Joubert, Prinsloo;
- **NRG:** Mrs. Sciolla, Messrs. Thijssen, Hendriks, Valko, van der Marck.