WP3

Integral experiments for validation of nuclear data and constraints on uncertainties

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ANDES semester Meeting, April 24, 2012, OECD/NEA Issy-Les-Moulineaux

<u>Task 1:</u> Scientific coordination (CEA)

<u>Task 2:</u> Definition of a common ND validation process (All)

<u>Task 3:</u> Analysis of integral experiments (All)

<u>Task 4:</u> Determination of the ND trends (All)

List of Deliverables

Milestones

WP3: Integral experiments for validation of ND and constraints on COV

Summary of the WP3 Deliverables:

Accurate Nuclear Data for nuclear Energy Sustainability

D3.1: Report on definition of the common strategy for ND validation by using integral experiments (07/2011)

On going work

D3.2: Report on analysis of MUSE experiment and C/E + sensitivity vectors (01/2012)

D3.3: Report on analysis of the ZPPR/SNEAK experiments and C/E + sensitivity vectors (01/2012)

D3.4: Report on criticality benchmark experiment and C/E + sensitivity vectors (05/2012)

Few weeks from now

D3.5: Report on analysis of the PROFIL experiment and C/E + sensitivity vectors (09/2012)

D3.6: Report on GUINEVERE VENUS-F analysis and C/E + sensitivity vectors (11/2012)

D3.7: Report on the analysis of constraints on nuclear data and resulting trends with respect to the use the C/E and Sensitivity data coming from the integral experiments (01/2013)

D3.8: Report on the analysis of the impact of the new evaluations with Covariance coming from WP2 and estimate the impact on the C/E and uncertainties of the integral experiments (05/2013)

Accurate Nuclear Data for nuclear Energy Sustainability

A draft Version D31 was proposed to WP3 co-workers on Nov. 9, 2011.

No remarks since this date → deliverable considered as **final**.

SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

Nuclear Fission and Radiation Protection

EURATOM

Project acronym: ANDES

Project full title: Accurate Nuclear Data for nuclear Energy Sustainability

Grant Agreement no.: FP7 – 249671

Workpackage N°: 3

Identification N°: D.3.1

Type of document: *Deliverable*

Title: **Definition of a generic strategy for the integral validation of nuclear data**

Dissemination Level: *PU*

Reference: *memorandum CEA/DEN/CAD/DER/SPRC/LEPh*

Status: *VERSION 0*

	Name	Partner	Date	Signature
written by:	D. BERNARD	CEA	11/9/2011	
WP leader:	D. BERNARD	CEA	11/9/2011	
IP Co-ordinator:	E. GONZALEZ	CIEMAT		

The aim of this deliverable is to describe the Uncertainty Quantification approach as a generic strategy for the validation of nuclear data within the 7th EU framework programme/ANDES Project [1].

This methodology is currently implemented in the global validation of APOLLO [2] or ERANOS [3] Neutron Code packages, with a special emphasis on the uncertainty management and its feedback on modern Nuclear Data assimilation and multi-parametric Transposition to Design parameters, for both thermal and fast complex nuclear systems. This strategy already used for the improvements of the European nuclear data files JEFF (namely from JEF-2.2 to JEFF-3.1.1), showed its rigorousness and its robustness [4] by the number of end users within various applications: FBR studies, criticality-safety, PWR and BWR cycle follow-up, fuel cycle studies.

The main goal is to distinguish calculation bias and nuclear data bias. Indeed, these two independent variables allow the exact total differential computation of the calculated integral parameters. To do so, a 2 steps methodology is applied:

- The first step consists in calibrating and reducing the calculation bias of the code.
- The second step consists in the interpretation of an experiment with a calibrated calculation tool and analyzing the discrepancy between calculation and experiment in term of nuclear data average value biais using S/U standard approach.

To be distributed…

SEVENTH FRAMEWORK PROGRAMME OF THE
EUROPEAN ATOMIC ENERGY COMMUNITY

Nuclear Fission and Radiation Protection

EURATOM

Project acronym: ANDES

Project full title: Accurate Nuclear Data for nuclear Energy Sustainability

Grant Agreement no.: FP7 – 249671

Workpackage N°: 3

Identification N°: D.3.3

Type of document: *Deliverable*

Title: **Analysis of the IRPhE experiments and C/E + sensitivity vectors**

Dissemination Level: *PU*

Reference: *memorandum IJS DP…..*

Status: *VERSION 0*

	Name	Partner	Date	Signature
written by:	I. KODELI	JSI	31/3/2012	
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IP Co-ordinator:	E. GONZALEZ	CIEMAT		

WP3: Integral experiments for validation of ND and constraints on COV

Accurate Nuclear Data for nuclear Energy Sustainability

Milestones of WP3:

M3.1: Description of the PROFIL numerical benchmark (11/2010)

M3.2 : Description of the VENUS-F core (GUINEVERE) experiment (11/2010)

M3.3: Code developments to implement the methodology (05/2011)

M3.4: Inter comparison on the analysis of different systems (11/2011)

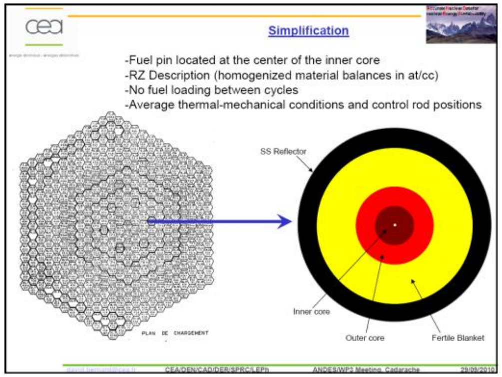
M3.5: Final comparison on the analysis of different systems (07/2012)

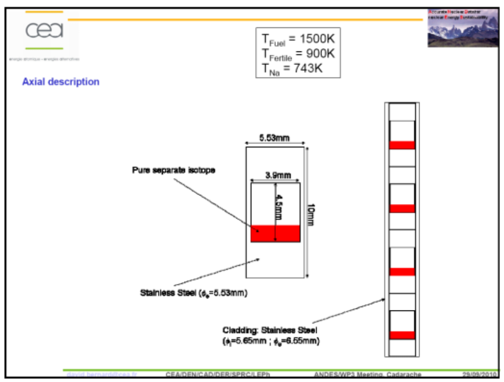
M3.6: Feedback on Nuclear Data (01/2013)

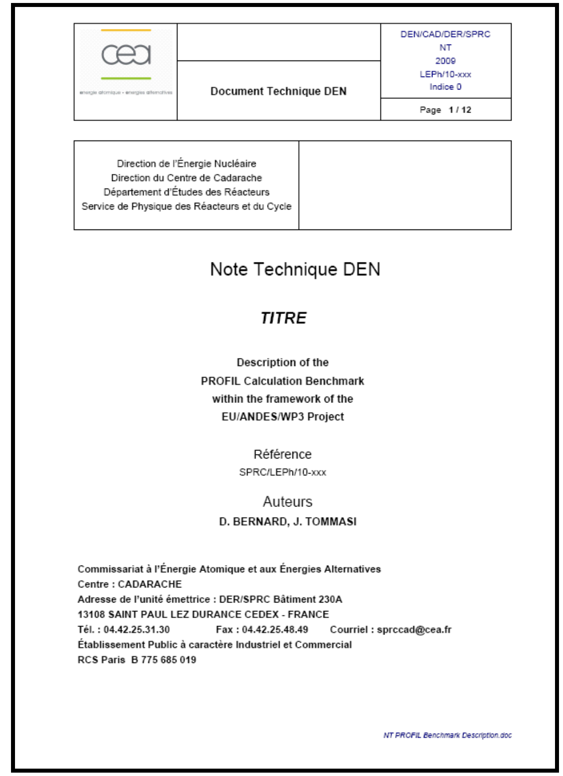
M3.7: Impact of the new covariance coming from WP2 to the analysis of the different experiments (05/2013)

TASK 3/SUBTASK 3: PROFIL Experiment made in PHENIX on separate isotopes

1/Benchmark for (transport+depletion) code validation







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Direction de l'Énergie Nucléaire
Direction du Centre de Cadarache
Département d'Études des Réacteurs
Service de Physique des Réacteurs et du Cycle

Note Technique DEN

TITRE

Description of the PROFIL Calculation Benchmark within the framework of the EU/ANDES/WP3 Project

Référence
SPRC/LEPh/10-xxx

Auteurs
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NT PROFIL Benchmark Description.doc

The first detailed description of the simplified benchmark was sent on December 2010.
A second one (bug corrected on burn-up determination…) was sent on March 2011,
A third on January 2012

Calculations with ERANOS, MURE, ALEPH (CIEMAT, SCK-CEN, CNRS, CEA)

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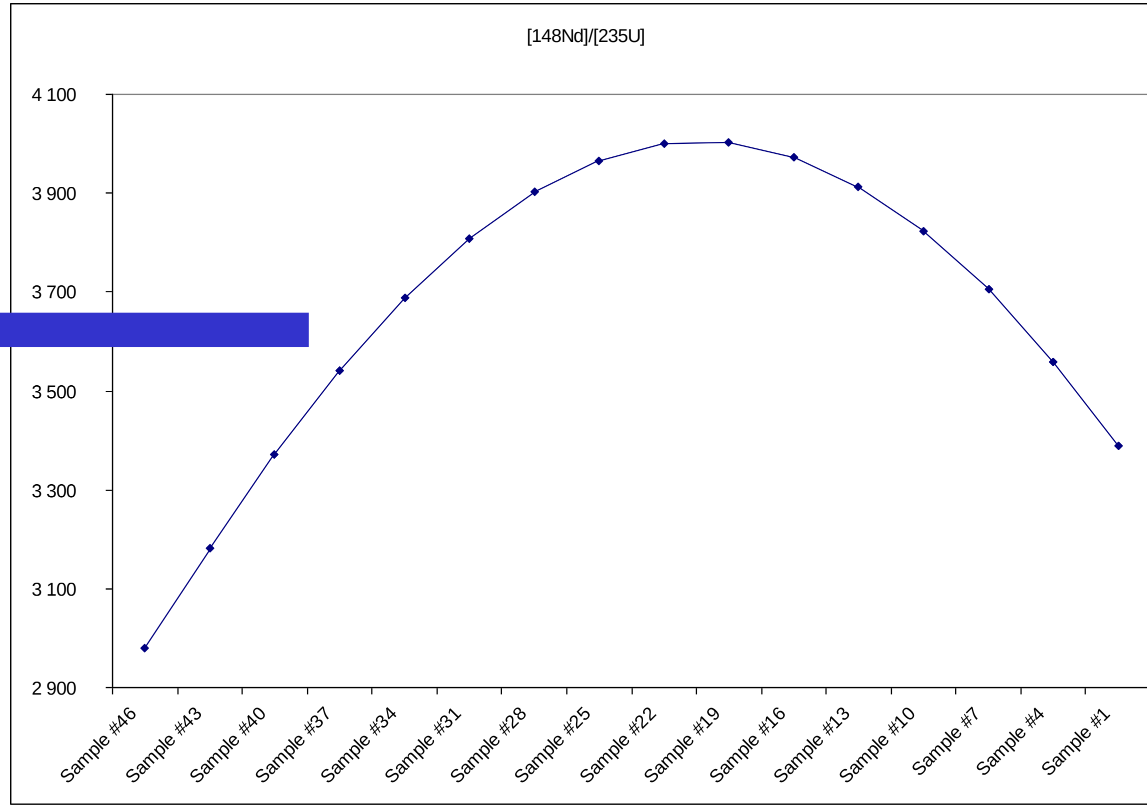
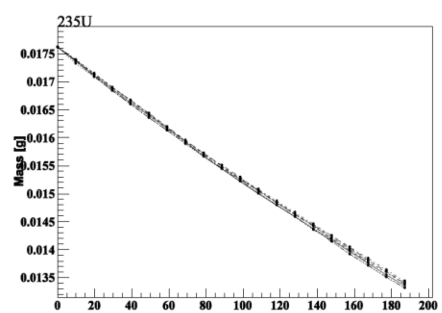
Fixed control rod



Waiting for EVOLCODE (CIEMAT), MURE (CNRS) results….

First results



Evolution of U-235 in the sample 22 of the PROFIL experiment for 10 different simulations

Accurate **N**uclear **D**ata for nuclear **E**nergy **S**ustainability

^{235}U doped samples

Targeted reaction	Concentration Ratii [ppm=10^{-6}]	Sample #46	Sample #43	Sample #40	Sample #37	Sample #34	Sample #31	Sample #28	Sample #25	Sample #22	Sample #19	Sample #16	Sample #13	Sample #10	Sample #7	Sample #4	Sample #1
^{235}U(n,2n)	[^{234}U]/[^{235}U]	125	134	141	148	154	159	163	165	167	167	165	163	159	154	149	142
^{235}U(n,γ)	[^{236}U]/[^{235}U]	48 474	51 676	54 650	57 316	59 621	61 525	62 992	63 999	64 528	64 571	64 126	63 199	61 808	59 973	57 727	55 112
^{235}U(n,γ)^{236}U(n,γ)^{237}U(β$^-$)	[^{237}Np]/[^{235}U]	798	902	1 003	1 098	1 183	1 256	1 313	1 353	1 374	1 376	1 358	1 322	1 267	1 197	1 114	1 020
^{235}U(n,f)	*[^{148}Nd]/[^{235}U]*	*2 979*	*3 183*	*3 372*	*3 542*	*3 688*	*3 809*	*3 903*	*3 967*	*4 000*	*4 002*	*3 973*	*3 913*	*3 823*	*3 705*	*3 559*	*3 390*
										Normalisation							

^{238}U doped samples

Targeted reaction	Concentration Ratii [ppm=10^{-6}]	Sample #44	Sample #41	Sample #38	Sample #35	Sample #32	Sample #29	Sample #26	Sample #23	Sample #20	Sample #17	Sample #14	Sample #11	Sample #8	Sample #5	Sample #2
^{238}U(n,2n)^{237}U(β$^-$)	[^{237}Np]/[^{238}U]	141	149	155	162	167	171	174	176	176	176	175	172	168	164	158
^{238}U(n,γ)^{239}U(β$^-$)^{239}Np(β$^-$)	[^{239}Pu]/[^{238}U]	21 780	22 944	23 989	24 899	25 663	26 275	26 727	27 016	27 141	27 099	26 891	26 518	25 983	25 290	24 446
^{238}U(n,γ)^{239}U(β$^-$)^{239}Np(β$^-$)^{239}Pu(n,γ)	[^{240}Pu]/[^{238}U]	482	537	590	638	680	715	742	759	767	764	752	730	699	661	615

^{239}Pu doped samples

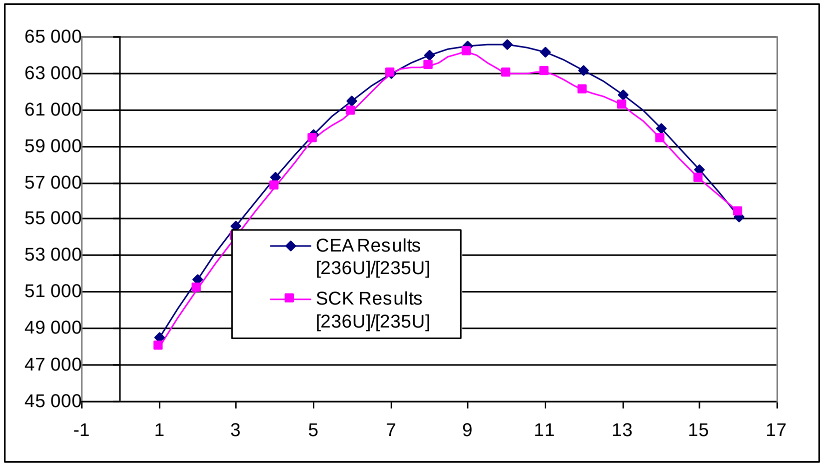
Targeted reaction	Concentration Ratii [ppm=10^{-6}]	Sample #45	Sample #42	Sample #39	Sample #36	Sample #33	Sample #30	Sample #27	Sample #24	Sample #21	Sample #18	Sample #15	Sample #12	Sample #9	Sample #6	Sample #3
^{239}Pu(n,2n)	[^{238}Pu]/[^{239}Pu]	49	52	54	57	58	60	61	62	62	61	61	60	58	56	54
^{239}Pu(n,γ)	[^{240}Pu]/[^{239}Pu]	43 709	46 269	48 591	50 625	52 333	53 684	54 657	55 236	55 413	55 184	54 554	53 533	52 140	50 397	48 339
^{239}Pu(n,γ)^{240}Pu(n,γ)	[^{241}Pu]/[^{239}Pu]	817	911	1 000	1 080	1 150	1 207	1 248	1 273	1 281	1 271	1 244	1 200	1 141	1 070	988

CODE SYSTEM = ERANOS-2.2.0 / JEFF-3.1

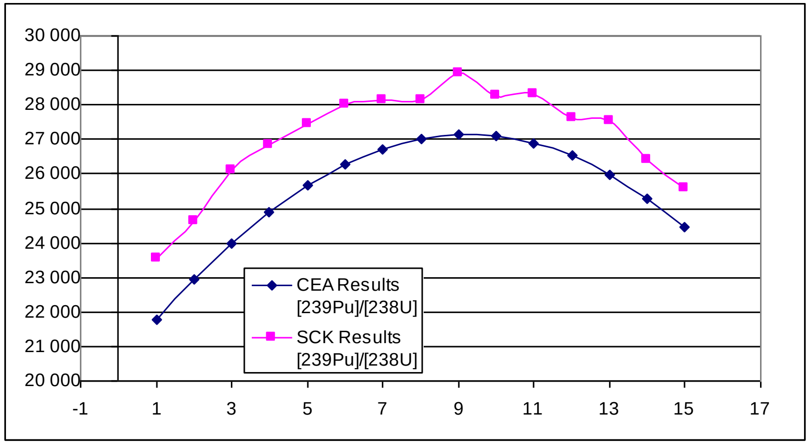
CEA Cadarache, EU/ANDES/WP3 (25/01/2012)

SCK / CEA results comparison, thanks to N. Messaoudi, E. Mbala Malambu work

^{236}U build-up in ^{235}U samples



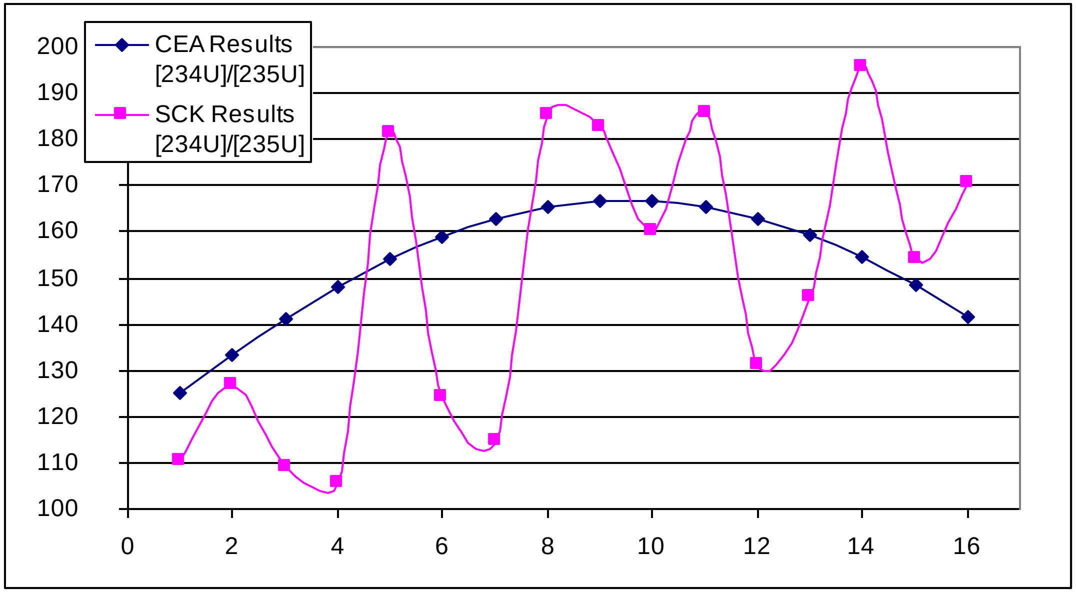
^{239}Pu build-up in ^{238}U samples



Axial burn-up is correct (same ^{148}Nd prediction)
Statistical convergence is ensure for major actinide with 4-5%
^{239}Pu build-up seems to be 5% over using ALEPH.

SCK / CEA results comparison, thanks to N. Messaoudi, E. Mbala Malambu work

Focus on statistical convergence for low reaction rate: ^{234}U build-up through $^{235}U(n,2n)$



SCK / CEA results comparison, thanks to N. Messaoudi, E. Mbala Malambu work

^{235}U doped samples

Targeted reaction	Concentration Ratii [ppm=10^{-6}]	Sample #46	Sample #43	Sample #40	Sample #37	Sample #34	Sample #31	Sample #28	Sample #25	Sample #22	Sample #19	Sample #16	Sample #13	Sample #10	Sample #7	Sample #4	Sample #1
^{235}U(n,2n)	[^{234}U]/[^{235}U]	-12%	-5%	-23%	-29%	18%	-22%	-30%	12%	10%	-4%	12%	-20%	-8%	27%	4%	21%
^{235}U(n,γ)	[^{236}U]/[^{235}U]	-1%	-1%	-1%	-1%	0%	-1%	0%	-1%	-1%	-2%	-2%	-2%	-1%	-1%	-1%	0%
^{235}U(n,γ)^{236}U(n,γ)^{237}U(β$^-$)	[^{237}Np]/[^{235}U]	3%	2%	1%	2%	1%	0%	2%	1%	2%	2%	0%	0%	2%	3%	1%	4%
^{235}U(n,f)	*[^{148}Nd]/[^{235}U]*	0%	0%	0%	0%	0%	0%	1%	0%	0%	-1%	0%	-1%	0%	1%	0%	1%
										Normalisation							

^{238}U doped samples

Targeted reaction	Concentration Ratii [ppm=10^{-6}]	Sample #44	Sample #41	Sample #38	Sample #35	Sample #32	Sample #29	Sample #26	Sample #23	Sample #20	Sample #17	Sample #14	Sample #11	Sample #8	Sample #5	Sample #2
^{238}U(n,2n)^{237}U(β$^-$)	[^{237}Np]/[^{238}U]	8%	8%	10%	53%	19%	51%	-10%	-5%	38%	20%	-17%	39%	-30%	14%	-33%
^{238}U(n,γ)^{239}U(β$^-$)^{239}Np(β$^-$)	[^{239}Pu]/[^{238}U]	8%	7%	9%	8%	7%	7%	5%	4%	7%	4%	5%	4%	6%	4%	5%
^{238}U(n,γ)^{239}U(β$^-$)^{239}Np(β$^-$)^{239}Pu(n,γ)	[^{240}Pu]/[^{238}U]	16%	17%	17%	16%	14%	14%	11%	8%	11%	8%	11%	9%	11%	9%	10%

^{239}Pu doped samples

Targeted reaction	Concentration Ratii [ppm=10^{-6}]	Sample #45	Sample #42	Sample #39	Sample #36	Sample #33	Sample #30	Sample #27	Sample #24	Sample #21	Sample #18	Sample #15	Sample #12	Sample #9	Sample #6	Sample #3
^{239}Pu(n,2n)	[^{238}Pu]/[^{239}Pu]	27%	-31%	-16%	-3%	60%	-29%	5%	30%	5%	-19%	-20%	-20%	-9%	35%	-17%
^{239}Pu(n,γ)	[^{240}Pu]/[^{239}Pu]	0%	0%	1%	1%	1%	4%	1%	2%	1%	2%	3%	3%	3%	3%	2%
^{239}Pu(n,γ)^{240}Pu(n,γ)	[^{241}Pu]/[^{239}Pu]	3%	6%	3%	4%	3%	8%	6%	7%	3%	6%	10%	7%	9%	8%	7%

Averaged discrepancies between SCK and CEA [%]

^{235}U Samples		
Concentration Ratii $[ppm=10^{-6}]$	Average	Std Dev
$[^{234}U]/[^{235}U]$	-3,0%	18,3%
$[^{236}U]/[^{235}U]$	-0,9%	0,7%
$[^{237}Np]/[^{235}U]$	1,5%	1,2%
$[^{148}Nd]/[^{235}U]$	0,0%	0,6%

^{238}U Samples		
Concentration Ratii $[ppm=10^{-6}]$	Average	Std Dev
$[^{237}Np]/[^{238}U]$	11,1%	26,9%
$[^{239}Pu]/[^{238}U]$	6,1%	1,5%
$[^{240}Pu]/[^{238}U]$	12,1%	3,2%

^{239}Pu Samples		
Concentration Ratii $[ppm=10^{-6}]$	Average	Std Dev
$[^{238}Pu]/[^{239}Pu]$	-0,2%	26,6%
$[^{240}Pu]/[^{239}Pu]$	1,8%	1,1%
$[^{241}Pu]/[^{239}Pu]$	5,9%	2,3%

1rst daughter seems to be slightly overestimated ^{239}Pu in ^{238}U: (6.1 1.5)%
Consequently, 2nd daughter is largely overestimated.

Now, one have to check precisely main reaction rates.

TASK 3/SUBTASK 4

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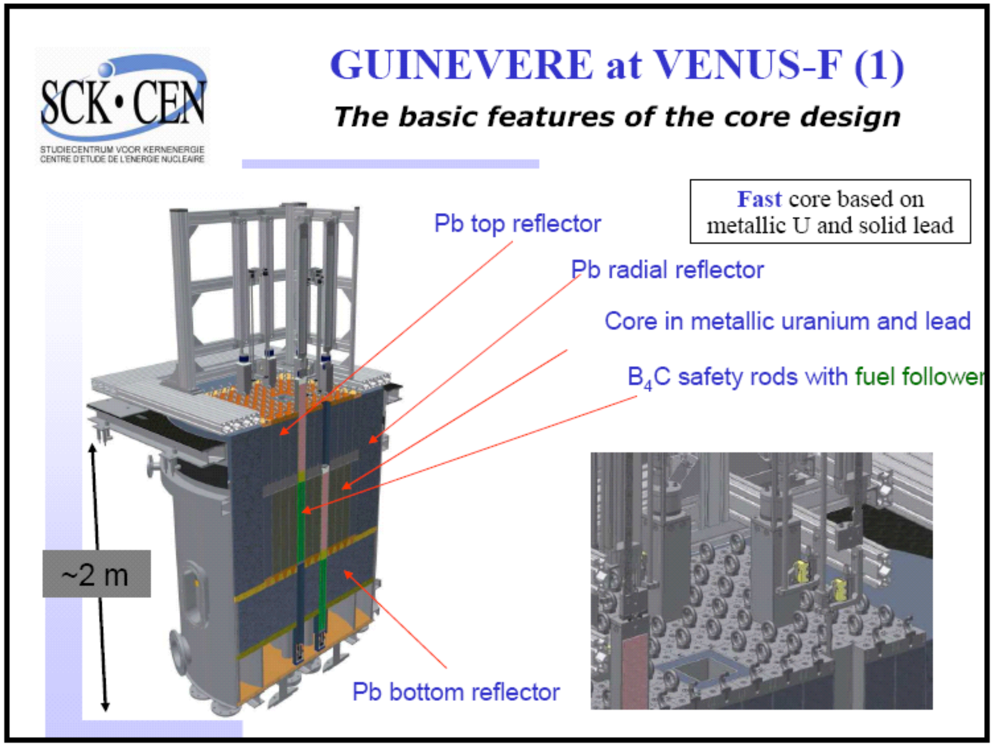

Criticality February 2011

SCK•CEN

RESTRICTED CONTRACT REPORT R-5184
SCK•CEN-WU/WU-3910.A000ANDES-0334/827/11-19

ANDES – Accurate Nuclear Data for Nuclear Energy Sustainability

Description of the VENUS-F Critical Core for Minor Actinides Fission Rates Calculations

Wim UYTTENHOVE
Anatoly KOCHETKOV

May 2011

NSP
SCK•CEN
Boeretang 200
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CNRS Description of MURE Code

SCK Description of ALPEH2.2 Code

SCK/CEN contribution to the Profile Experiment benchmark

Calculation Details

N. Messaoudi and E. Mbala Malambu

The depletion calculation was performed with ALEPH 2.2 code [5]. ALEPH (SCK/CEN's) home-made wrapping code coupling any version of the MCNP/X code with a burn-up routine.

The core criticality (k-code mode) calculation was carried out using, as Monte Carlo code, the MCNPX (version 2.7.0) [1, 2] and tracking 10^6 particle histories per cycle, over 1000 active cycles and 100 inactive ones, to generate the fission spectrum for each burnable zone, namely the 46 sample zones plus the fissile material zones. Nuclear data from JEFF-3.1.2 library [3, 4] was used.

The specified power normalisation criterion, viz., the ($^{148}Nd/^{235}U$) ratio of 4000 ppm, was fulfilled at the core power of 600 MW.

References

1. D. B. Pelowitz, ed., MCNPX User's Manual, Version 2.7.0, Los Alamos National Laboratory report LA-CP-11-00438 (April 2011).
2. J. S. Hendricks, et al., MCNPX 2.7.0 Extensions, Los Alamos National Laboratory report LA-UR-11-02295 (April 2011).
3. JEFF-3.1.2, http://www.oecd-nea.org/dbforms/data/eva/evatapes/jeff_31/JEFF312/ (2012).
4. A.Santamarina, et al., "The JEFF-3.1.1 Nuclear Data Library, JEFF Report 22," NEA No. 6807, OECD (2009).
5. A.Stankovskiy and G.Van den Eynde, "ALEPH 2.2 – A Monte Carlo Bunr-Up Code", SCK•CEN-R-5267 (2012).

Code developments to implement the methodology

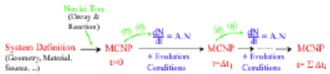
The goal of the work package 3 of the ANDES project is to agree on a common methodology to use the integral experiment to improve and validate nuclear data and to constrain their uncertainties. To reach this goal, several integral experiments of the public domain are used in order to estimate the impact of new nuclear data evaluation and see which code developments have to be made to implement the analysis methodology.

Most of integral experiments need rather high neutron flux which means burn-up calculations and consequently fuel evolution. The MURE Code (MCNP Utility for Reactor Evolution), which uses MCNP as a neutron transport solver, could be used for integral experiment analysis.

The MURE Code

The main aim of the MUREpackage is to perform nuclear reactor time-evolution using the widely-used particle transport code MCNP (a Monte Carlo code which is mostly written in FORTRAN). Many depletion codes exist for determining time-dependent fuel composition and reaction rates. These codes are either based on solving Boltzman equation using deterministic methods or based on Monte-Carlo method for neutron transport. However, the way to control (or interact with) the evolution are either limited to specific procedure and/or difficult to implement.

The material evolution is calculated by solving the corresponding Bateman's equations. The code simulates the evolution of the fuel within a given reactor over a time period of up to several years, by successive steps of MCNP calculation and numerical integration of Bateman's equations. Each time MCNP is called, the reactor fuel composition will have changed due to the fission/capture/decay process occurring inside. Changes in geometry, temperature, external feeding or extraction during the evolution can also be taken into account. MCNP input files are built automatically and the user can choose the library as soon as it is in the right ace format.



To solve the Bateman's equation, there are 3 levels of time discretization:

- The first level is the MCNP step, i.e., the number of Δt_i or MCNP runs. These steps are user-defined and are generally not regular.
- The second level is the discretization within a Δt_i. Each Δt_i is divided in N_{RK} equally spaced Runge-Kutta δt steps (which we'll also refer to as RK steps). At each $t = k\delta t$, Bateman equations are built with given cross-sections. Special method controlling the evolution could be called a these times (e.g. the flux is renormalized to keep the constant power ...).

Thank you for your attention