INTERNATIONAL COMPARISON FOR TRANSITION SCENARIO CODES INVOLVING COSI, DESAE, EVOLCODE, FAMILY AND VISION

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Outlines

- Introduction and background
- Codes Selected for the benchmark
- Scenario assumptions
- Results
- Conclusions

Introduction and background

The WPFC / FCTS

The expert group on Fuel Cycle Transition Scenario (FCTS) is working under the guidance of the Working Party on scientific issues of the Fuel Cycle (WPFC) of the NEA

Objective of the WPFC / FCTS group :

National, regional or worldwide transition scenarios are studied inside this expert group with different existing tools devoted to scenario studies. After a review on existing national scenarios, one of the first missions of this expert group was to compare the existing scenario codes in term of capabilities, modelling and results.

Codes Selected for the benchmark

5 codes were selected, among the available existing codes :

COSI 6 developed at CEA-France,

DESAE2.2 developed at ROSATOM-Russia, operated by AECL

EVOLCODE developed at CIEMAT-Spain,

FAMILY21 developed by JAEA-Japan

VISION2.2 developed at INL-USA.

These codes have different output and capabilities
⇒The benchmark will assess the common capabilities of the codes

Codes Selected for the benchmark

	COSI 6	DESAE 2.2	EVOLOCODE	FAMILY21	VISION 2.2
Language	Java		Fortran	Microsoft Visual Basic	System Dynamics/ Power Sim
User interface	Yes	Yes	Text interface	Yes	Yes
Simultaneous advanced technologies scenarios	Any combination of LWR, HTR,HWR, FR, ADS + different types of fuels	Yes	Any reactor with any fuel	Any combination of LWR, HWR, FR and ADS + different types of fuels	One-tier, two-tier scenarios (+ choice of the number of recycling)
Isotopics tracking	Y (Isotopes of U/PU/MA/200 FP)	U, Pu, minor actindes	Yes (~3300 isotopes)	Yes (Isotopes of U/Pu/MA/ 880 FP)	Yes (Follows up to 81 isotopes)
Calculation of depletion in cores	Depletion code CESAR with one-group cross sections libraries Direct coupling with ERANOS possible	No coupling with transmutation code	Creation of one group cross sections with EVOLCODE2. Possibility of choosing reference libraries.	Stored depletion matrix based on results of depletion calculation by the ORIGEN2 code	Precalculated Fuel recipes with interpolation (as a function of the number of cycles)

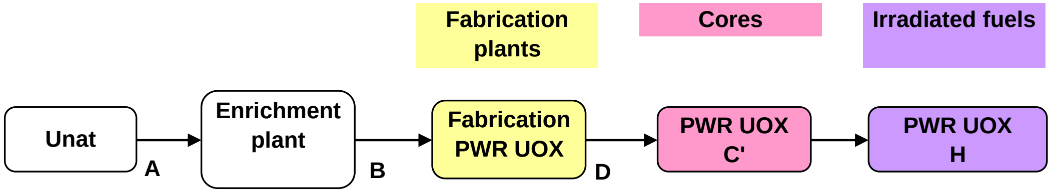
Codes Selected for the benchmark

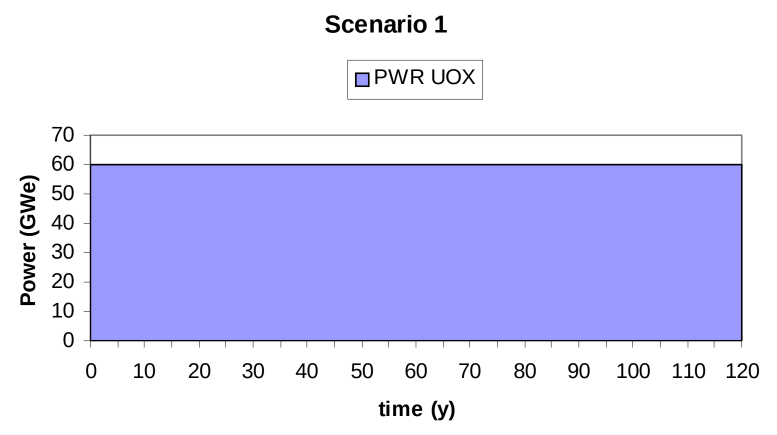
	COSI 6	DESAE 2.2	EVOLOCODE	FAMILY21	VISION 2.2
Start Up and Shut Down fuel loads	Yes	Startup only	Yes	Yes	No
Front-End fuel cycle facilities	All facilities represented	Enrichment	Enrichment	Enrichment Fabrication	Enrichment Fabrication
Reprocessing plants	Represented	Represented	Represented	Represented	Represented
Spent fuel to be reprocessed	User choice: “first-in first-out” or “last-in-first-out”	“first-in first out” only	User choice: “first-in first-out” or “last-in-first-out”	User choice: “first-in first-out” or “last-in-first-out”	User choice: “first-in first-out” or “last-in-first-out”
High Level waste package calculations	Yes + time dependant radiotoxicity and decay heat	No	No	Yes	Yes
Repository requirement assessment	Yes	No	No	No	Yes

Scenario Assumptions

=> 3 scenarios with 3 different levels of complexity

Scenario 1 : open cycle nuclear fleet

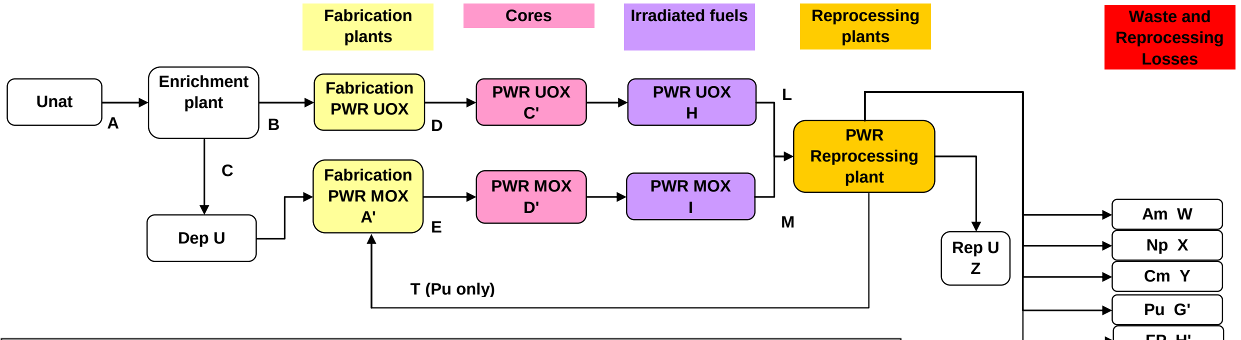




- No transition in the reactor park
- Accumulation of spent fuel without reprocessing

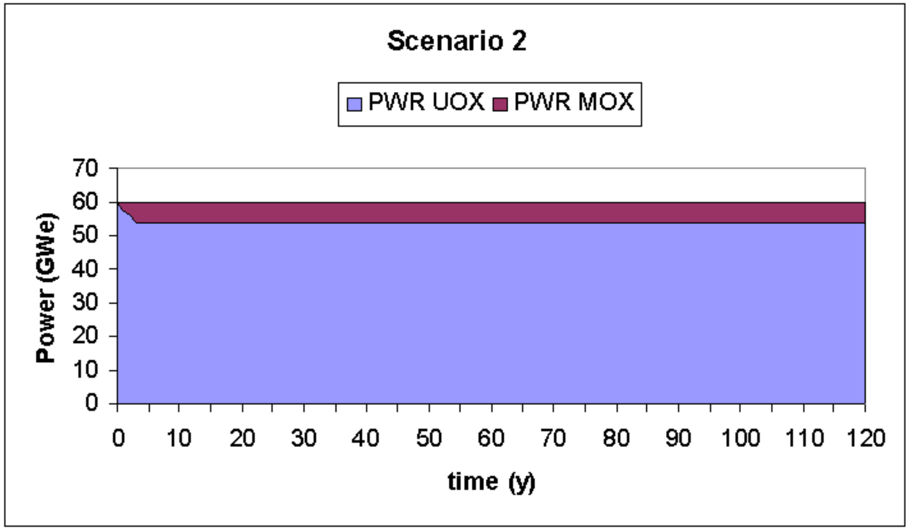
Scenario Assumptions

Scenario 2 : single recycling of Pu in the LWR



Fabrication plants
Cores
Irradiated fuels
Reprocessing plants
Waste and Reprocessing Losses

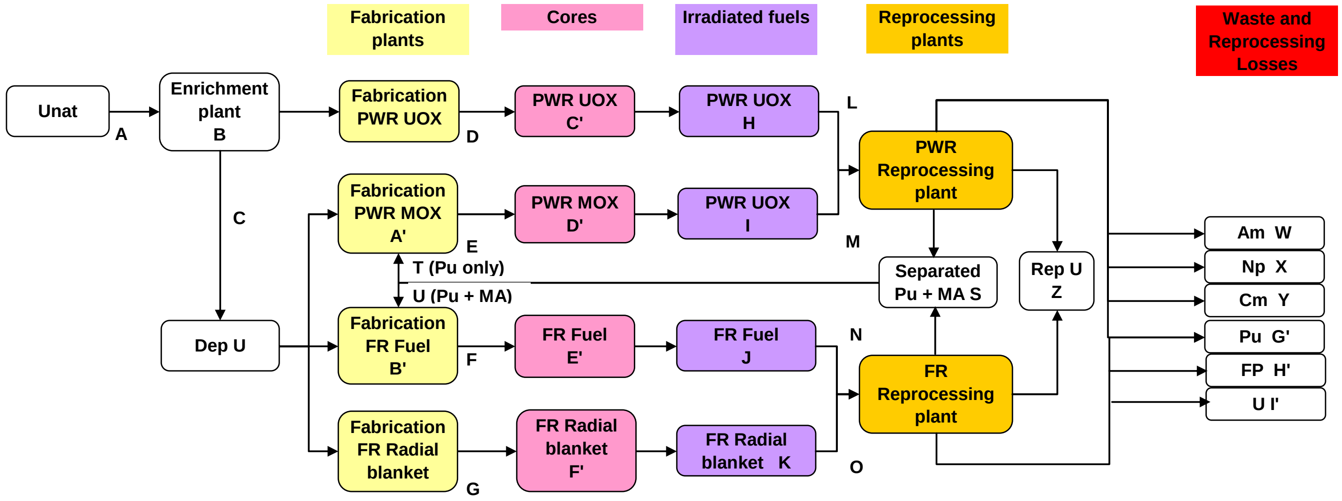
Unat
A
Enrichment plant
B
C
Dep U
Fabrication PWR UOX
D
Fabrication PWR MOX A'
E
PWR UOX C'
PWR MOX D'
PWR UOX H
PWR MOX I
L
M
PWR Reprocessing plant
T (Pu only)
Rep U Z
Am W
Np X
Cm Y
Pu G'
FP H'
U I'

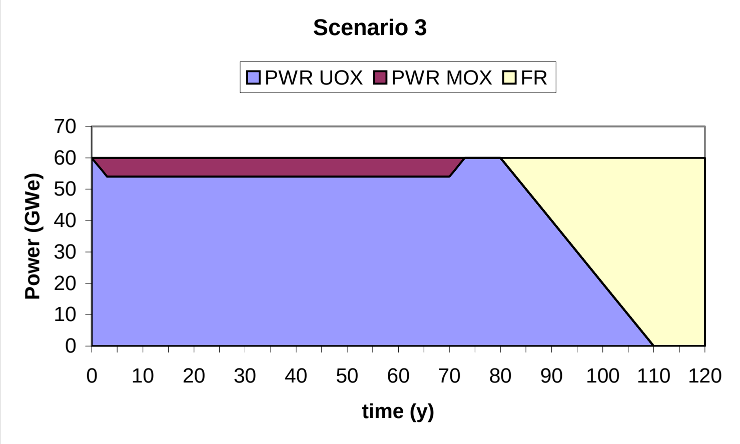


- No transition in the reactor park
- Reprocessing of PWR UOX spent fuel, MOX is not reprocessed

Scenario Assumptions

Scenario 3 : Recycling of Pu and MA in the Fast Reactors





- Transition from LWR to fast reactors
- Reprocessing of PWR UOX, MOX and FR spent fuel (fissile + blankets),

Scenario Assumptions

Reactor and fuel assumptions

		PWR UOX	PWR MOX	FR
Fuels / blankets				
Fissile Burnup	GWd/tHM	60	60	136
Axial blankets burnup	GWd/tHM	-	-	15
Radial blankets burnup	GWd/tHM	-	-	25
Minimum cooling time	y	5	5	2
Fabrication time	y	2	2	2
Fresh fuel ^{235}U enrichment	%	4,95	0,25	0,25
Moderation ratio		2	2	-
Equivalent Pu content	%	-	-	14,5
Cores				
Electrical nominal power	GW	1,5	1,5	1,45
Efficiency	%	34	34	40
Load factor	-	0,8176	0,8176	0,8176
Heavy metal masses				
Fissile	t	128,9	128,9	41,4
Axial blanket	t	-	-	18,0
Radial blanket	t	-	-	13,5
Breeding gain		-	-	≈1
Cycle length	EFPD	410	410	340
Core fraction (fuel)		1/4	1/4	1/5
Core fration (radial blankets)		-	-	1/8
Reprocessing plants				
Priorities		First in –first out	First in –first out	First in –first out. First fuel then blankets
Losses (U and Pu)	%	0,1	0,1	0,1
Initial Spent fuels				
		PWR UOX	**PWR MOX**	**FR**
Initial mass	t	10000	0	0

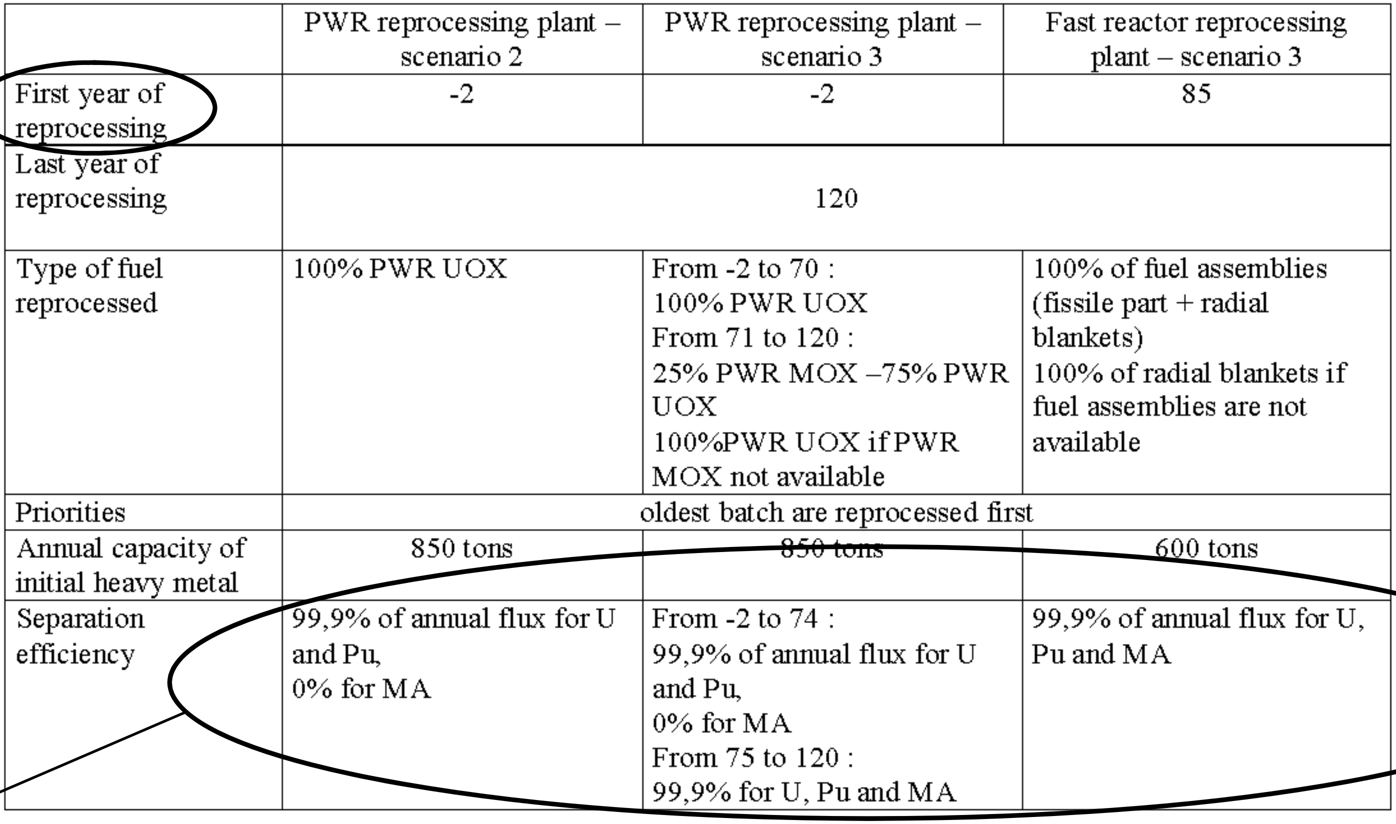
FR cores with 3 zones

Not considered by some of the codes

Initialization effect

Scenario Assumptions

Reprocessing assumptions

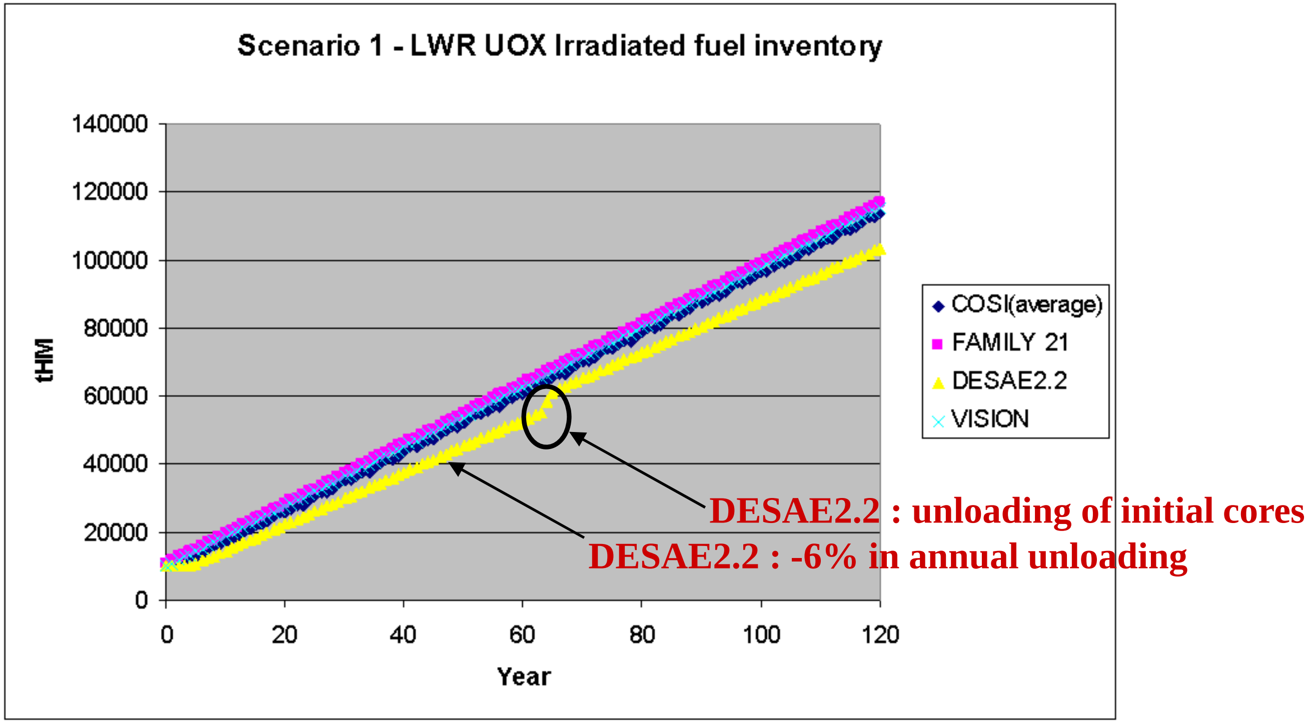


	PWR reprocessing plant – scenario 2	PWR reprocessing plant – scenario 3	Fast reactor reprocessing plant – scenario 3
First year of reprocessing	-2	-2	85
Last year of reprocessing	120		
Type of fuel reprocessed	100% PWR UOX	From -2 to 70 : 100% PWR UOX From 71 to 120 : 25% PWR MOX –75% PWR UOX 100%PWR UOX if PWR MOX not available	100% of fuel assemblies (fissile part + radial blankets) 100% of radial blankets if fuel assemblies are not available
Priorities	oldest batch are reprocessed first		
Annual capacity of initial heavy metal	850 tons	850 tons	600 tons
Separation efficiency	99,9% of annual flux for U and Pu, 0% for MA	From -2 to 74 : 99,9% of annual flux for U and Pu, 0% for MA From 75 to 120 : 99,9% for U, Pu and MA	99,9% of annual flux for U, Pu and MA

Specification of Initialization phase

Detailed specification of separation capacity

Results : spent fuel



DESAE2.2 : unloading of initial cores

DESAE2.2 : -6% in annual unloading

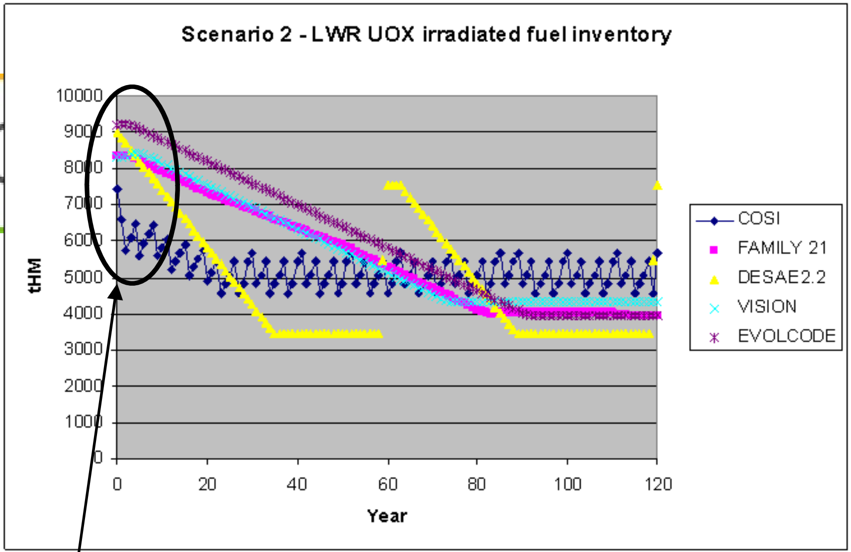
All the codes are very close, except DESAE 2.2 for which the dicrepancies remain unexplained.

The year of the first unloading of spent fuel has also an impact on the accumulated LWR UOX irradiated fuel. The values given by the codes are:

COSI:	**year 3**
FAMILY 21:	**year 2**
VISION:	**year 1**
DESAE 2.2:	**year 1**

=> Importance of initialization phase

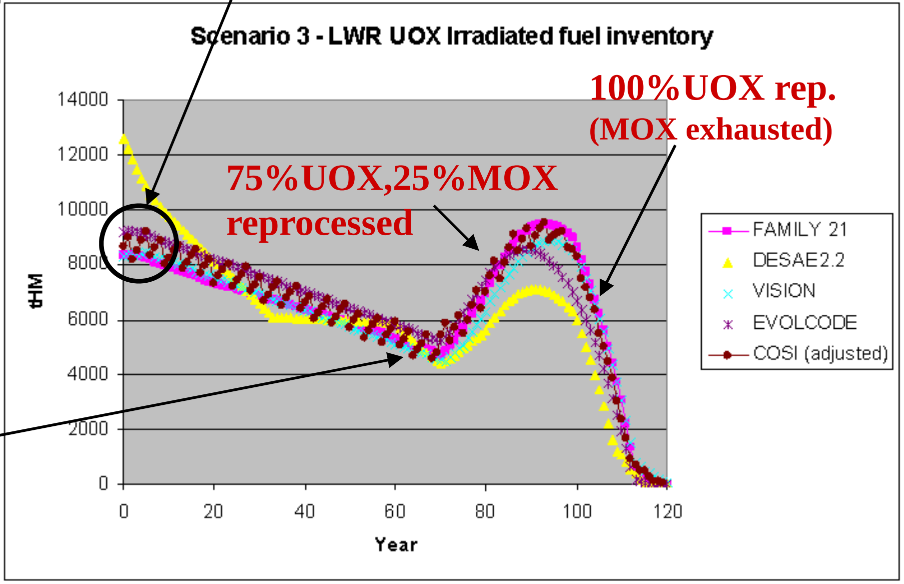
Results : spent fuel



⇒**Importance of initialization assumptions**

- Same initialization assumptions have been used for the scenario 3 :
- Behaviour of DESAE 2.2 remains unexplained

Different initialization assumptions in the first step of scenario 2=> Spent fuel stabilization occures at different years

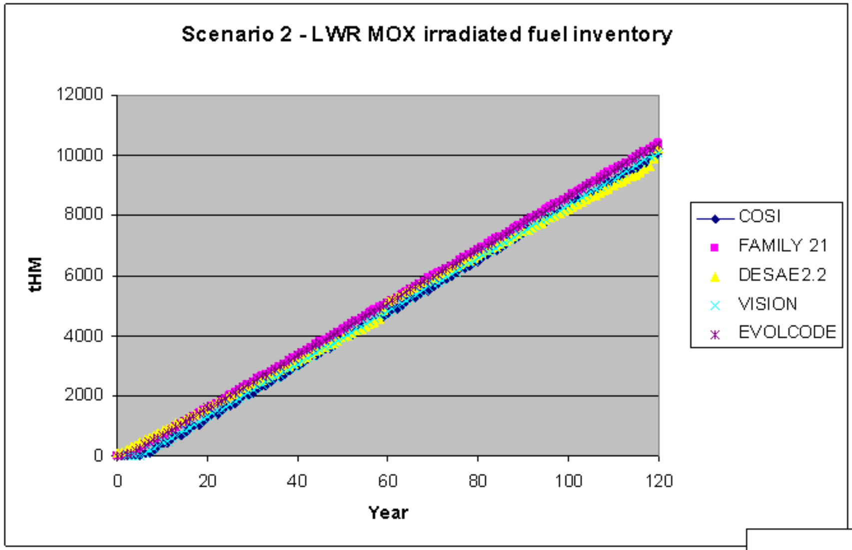


100%UOX rep.
(MOX exhausted)

75%UOX,25%MOX reprocessed

LWR UOX inventory has reached the minimum value =
Minimum cooling time (5 years) x Annual unloading (790 tons)

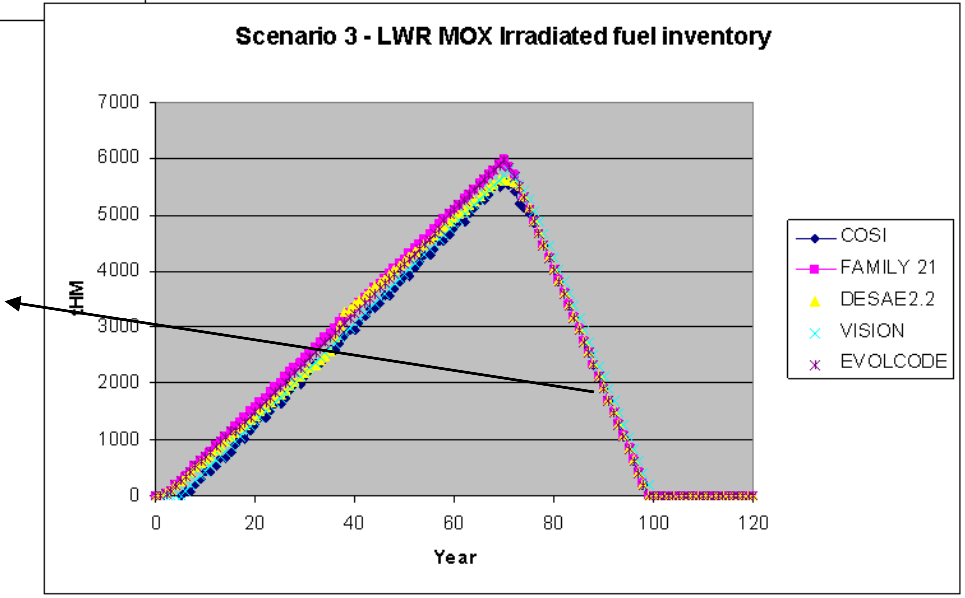
Results : spent fuel



In the scenario 2, LWR MOX spent fuel is not reprocessed

The differences in MOX spent fuel inventory are a consequence of

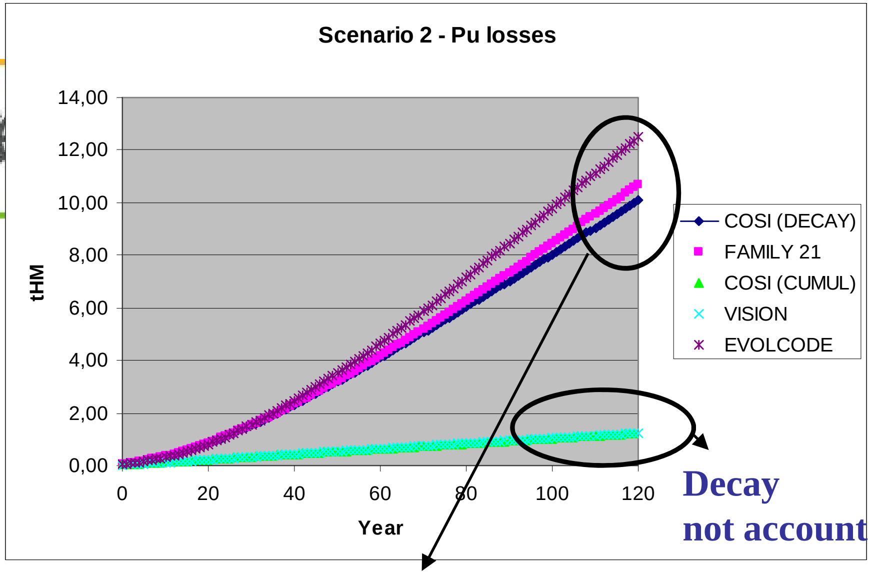
- **differences in MOX annual fabrication,**
- **differences in the year of first MOX unloading : year 3 for EVOLCODE, year 5 for COSI, 6 for VISION, 2 for FAMILY21, 0 for DESAE.**



In the scenario 3, LWR MOX spent fuel is reprocessed to fed the FR with Plutonium

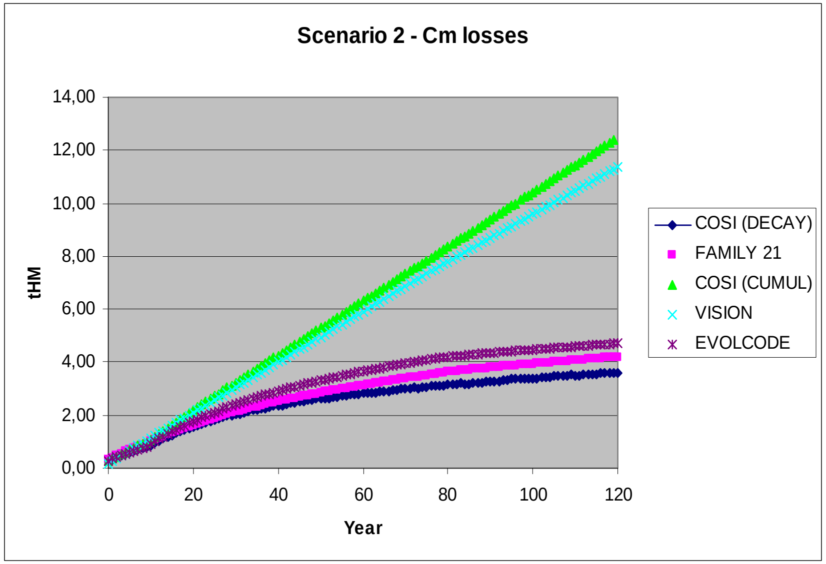
MOX exhausted around year 100.

Results : Pu and MA losses



Decay
not accounted

The decay of Cm244 to Pu240 (period = 18 years) is the main contributor of Pu inventory in the HLW…

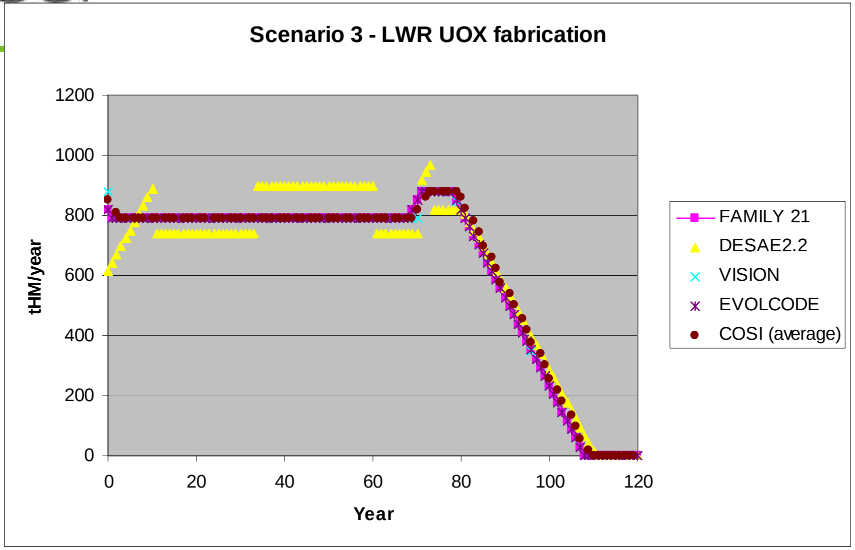


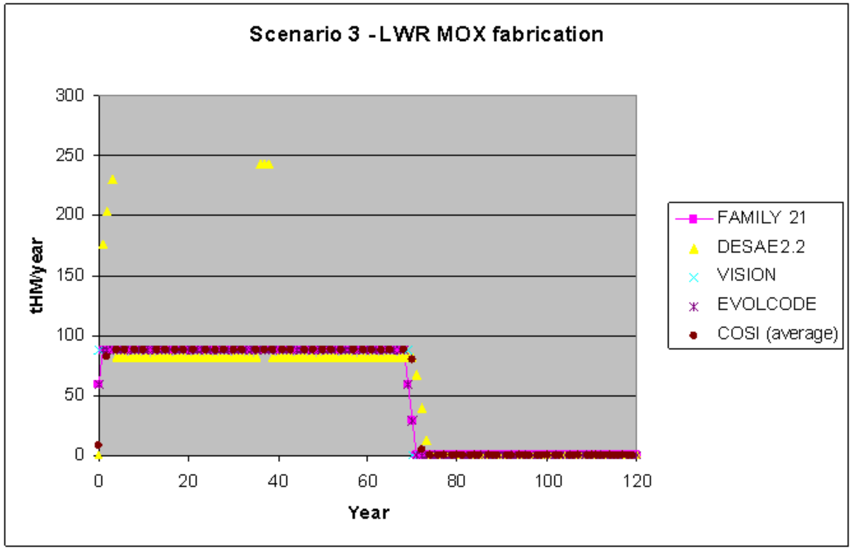
… and tends to stabilize Cm inventory

4 factors can explain the discrepancies in MA losses :
1.- A different reprocessing amount of spent fuel,
2.- The age of spent fuel at reprocessing step
3.- Each code has applied its own neutron spectra and cross sections, leading to slightly different isotopic compositions in the spent fuel.
4.- COSI, EVOLCODE and FAMILY codes account for the decay of nuclear waste after reprocessing, whereas VISION does not consider this decay.

Results

LWR Fuel Fabrication





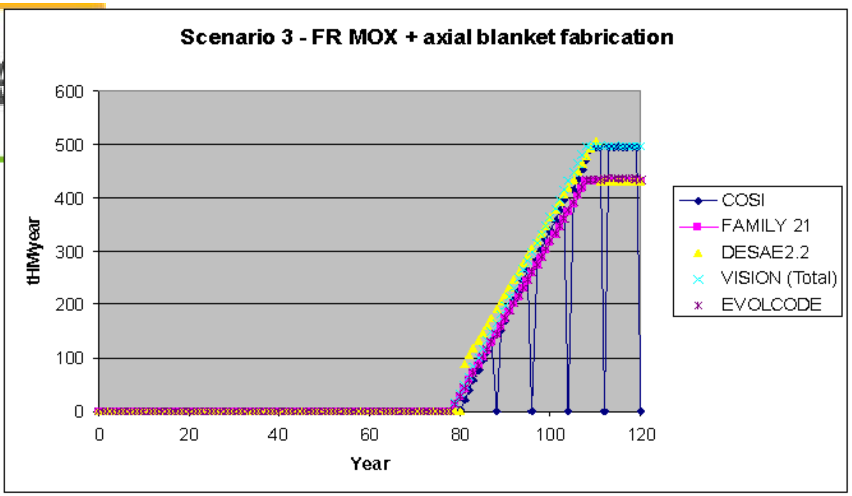
In all the codes, fabrication of fuel depends on demand

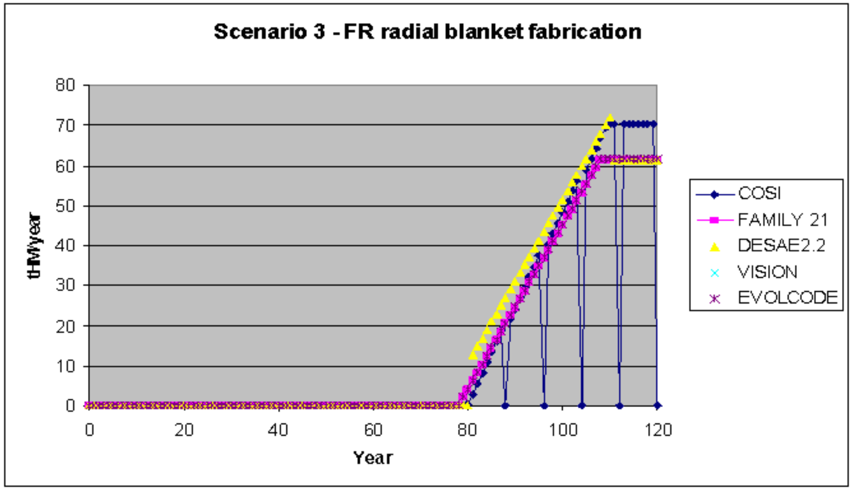
COSI, FAMILY21, EVOLCODE and VISION calculate the same values for UOX and MOX fuel fabrication.

For DESAE2.2, LWR UOX and MOX fabrication is different.

Results

Fast Reactors Fuel Fabrication



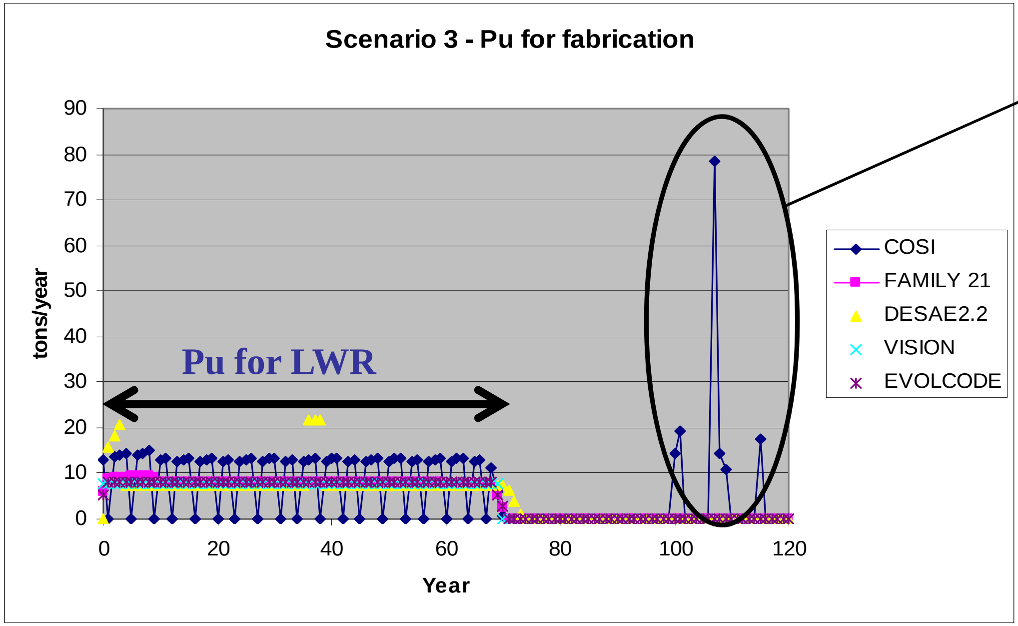


	COSI	FAMILY	VISION	EVOL CODE	DESAE
Annual average MOX + axial blanket fabrication after year 110	435,0 tons	431,8 tons	--	435,4 tons	431,8 tons
Annual average radial blanket fabrication after year 110	61,8 tons	61,3 tons	--	61,8 tons	61,3 tons
Total	496,8 tons	493,1 tons	497,4 tons	497,2 tons	493,1 tons

⇒Discrepancies in the transition phase (from year 80 to 110)

⇒Agreement in the equilibrium phase (after year 110)

Results : Pu for fabrication



In case of lack of TRU for Fast Reactors, COSI uses separated Pu from LWR

	COSI	FAMILY	VISION	EVOL CODE	DESAE
Annual Pu mass	9,45 tons	8,39 tons	7,83 tons	7,93 tons	7,32 tons
Average heavy metal mass	88,9 tons	87,84 tons	87,77 tons	87,83 tons	82,07 tons
Pu fraction, year 4 to 64 (%)	**10,62 %**	**9,56 %**	**8,92 %**	**9,03 %**	**8,92%**

In COSI, Pu fraction in LWR MOX is calculated with an equivalence model taking into account Pu isotopic composition, final burnup of the fuel and core fraction.

In EVOLCODE, Pu fraction is set at 9,03%

Conclusions (1/3)

The results and the analysis of the calculations lead to the following conclusions:

1) The general trends observed for each code are the same for the 3 scenarios calculated in the benchmark.

2) All the scenario codes give very close results for the scenario 1. However, there is neither transition nor reprocessing in this scenario.

3) For the scenario 2 and 3, the general trends are the same but some discrepancies appear. The comparison of the results demonstrates the importance of initial assumptions and the common interpretation of the assumptions and results.

4) A tuning of the assumptions is often necessary because of the difference of interpretation for initial conditions and some missing assumptions which may appear. Thus, several iterations can be necessary to converge.

Conclusions (2/3)

5) Once the tunings and iterations has been made, some remaining discrepancies subsist and come mainly from

- the capacity of modeling of the codes,
- the transition periods in the scenarios 2 and 3,
- the differences in physical models : irradiation and decay calculations
- the flexibility offered by the different codes.

This benchmark was limited to the comparison in heavy elements material flows. A comparison for isotopes would have probably led to other discrepancies and would have necessitated a more detailed investigations on the physical models used by the codes.

Conclusions (3/3)

2 documented benchmark on scenario codes

NEA benchmark :
COSI, DESAE, EVOLCODE, FAMILY, VISION

MIT benchmark :
CAFCA, COSI, DANESS, VISION

“NEA/NSC/WPFC,
Expert group on fuel cycle transitions scenarios,
Benchmark on Scenario codes”
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“A Benchmark Study of Computer Codes for System Analysis of the Nuclear Fuel Cycle »
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