CP ESFR: Collaborative Project for a European Sodium Fast Reactor

Core studies

http://www.cp-esfr.eu

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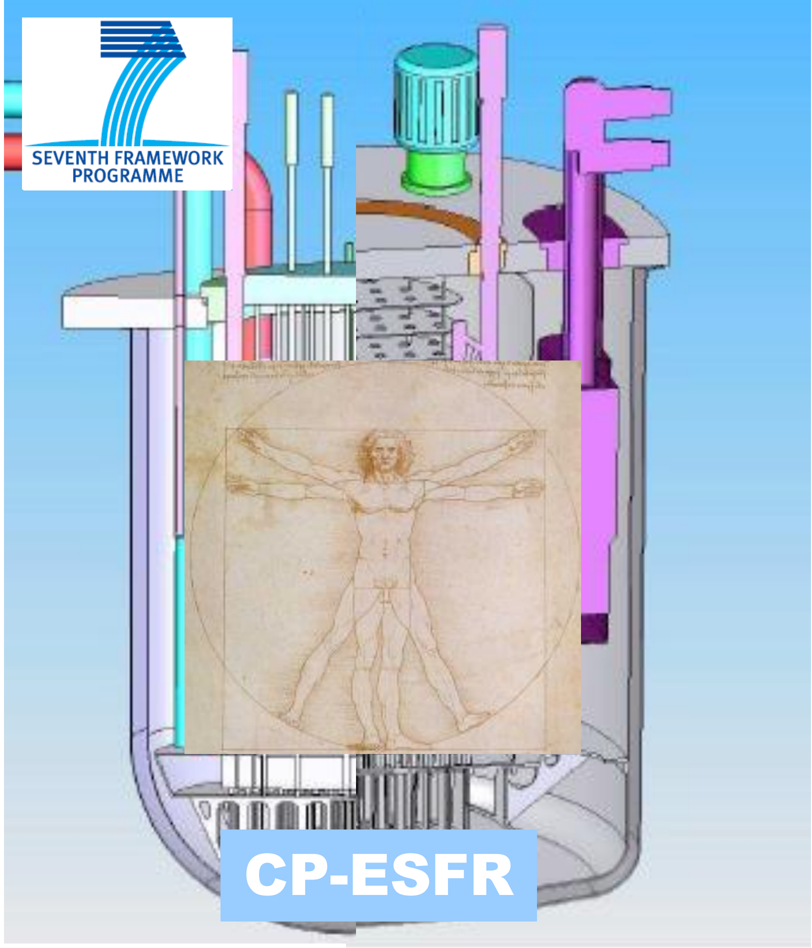


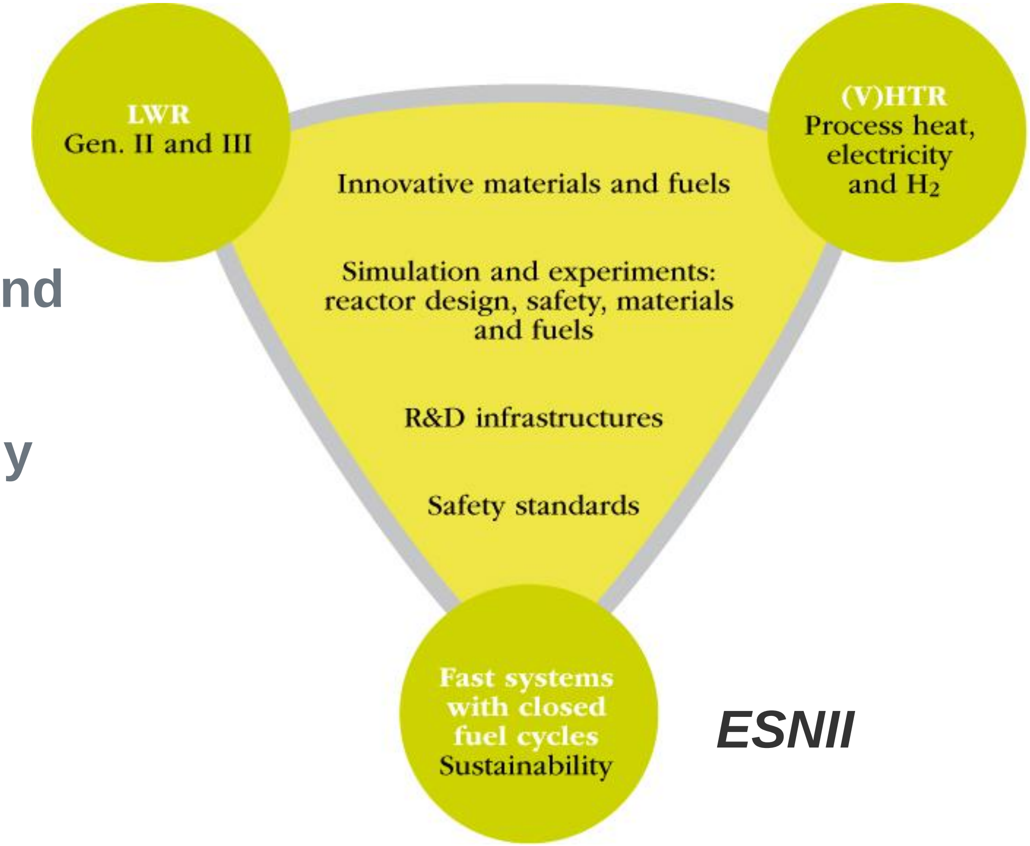
Outline

- CP ESFR Background
- Oxide core optimization
- Carbide core optimization
- Conclusions

CP ESFR Background

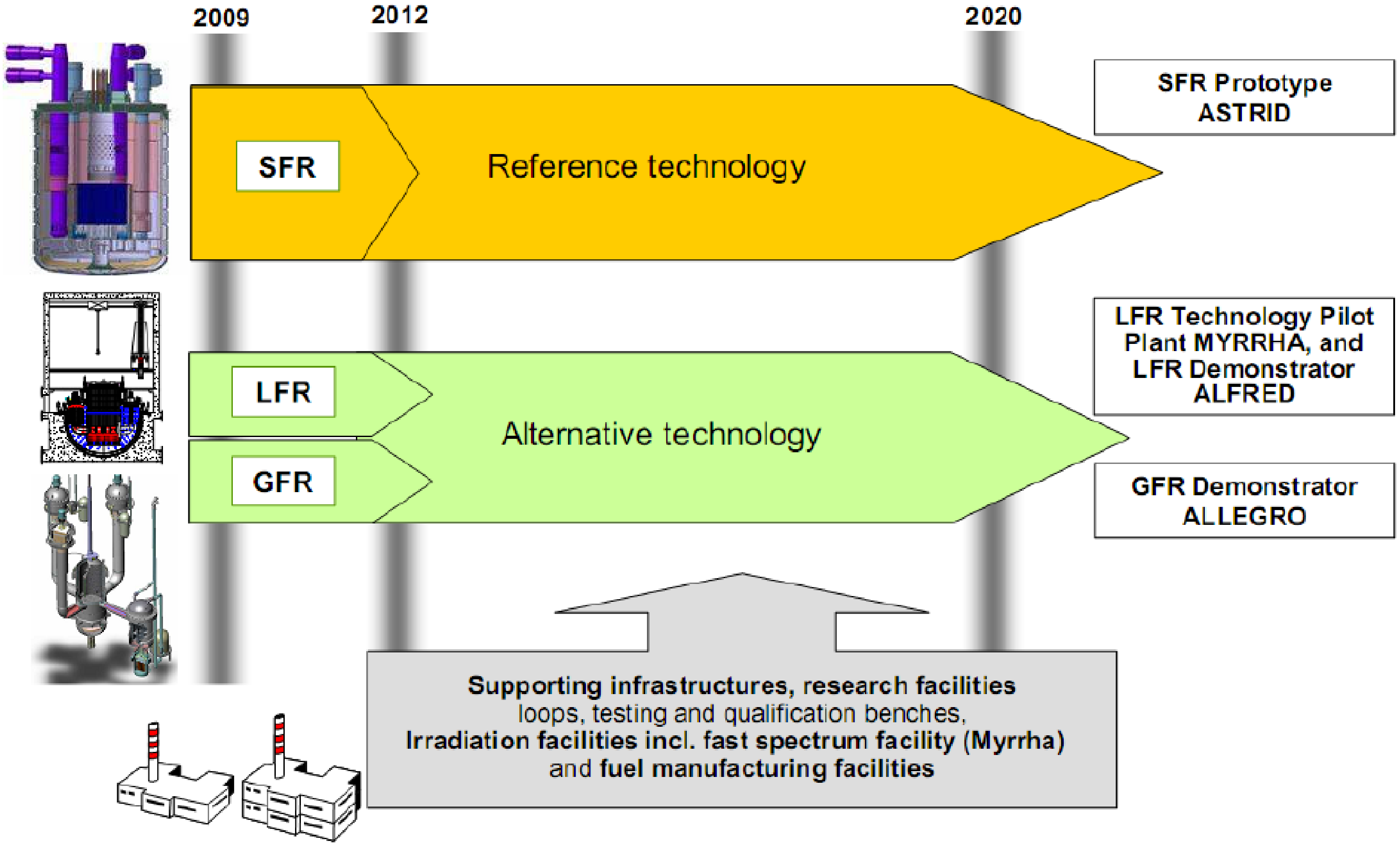
SNETP
SUSTAINABLE NUCLEAR ENERGY
TECHNOLOGY PLATFORM

- Shared vision on technological options and R&D strategy.
- Agenda on R&D strategy
- Basis for Euratom FPs
- Organized in 3 tracks



CP ESFR Background

- 2040: Target for the deployment of Gen IV Fast Neutron Reactors with Closed Fuel Cycle.



2009

2012

2020

SFR

Reference technology

SFR Prototype ASTRID

LFR

GFR

Alternative technology

LFR Technology Pilot Plant MYRRHA, and LFR Demonstrator ALFRED

GFR Demonstrator ALLEGRO

Supporting infrastructures, research facilities
loops, testing and qualification benches,
Irradiation facilities incl. fast spectrum facility (Myrrha)
and **fuel manufacturing facilities**

CP ESFR Objectives

- Improved safety: achievement of a robust architecture vis à vis of abnormal situations and the robustness of the safety demonstrations.
- Financial risk comparable to other means of energy production through the improvement of the economic competitiveness and the reliability and availability of the system
- A flexible and robust management of the nuclear materials. Waste reduction through MA burning.
- Contribution to the re-built of the European expertise on SFRs.
- Comparison of different Pool and Loop types plant designs and evaluation of different core design features

CP ESFR - Description of the Project

amec

AnsaldoNucleare
Una Società Finmeccanica

AREVA

RSE
Ricerca Sistema Energetico

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

EDF

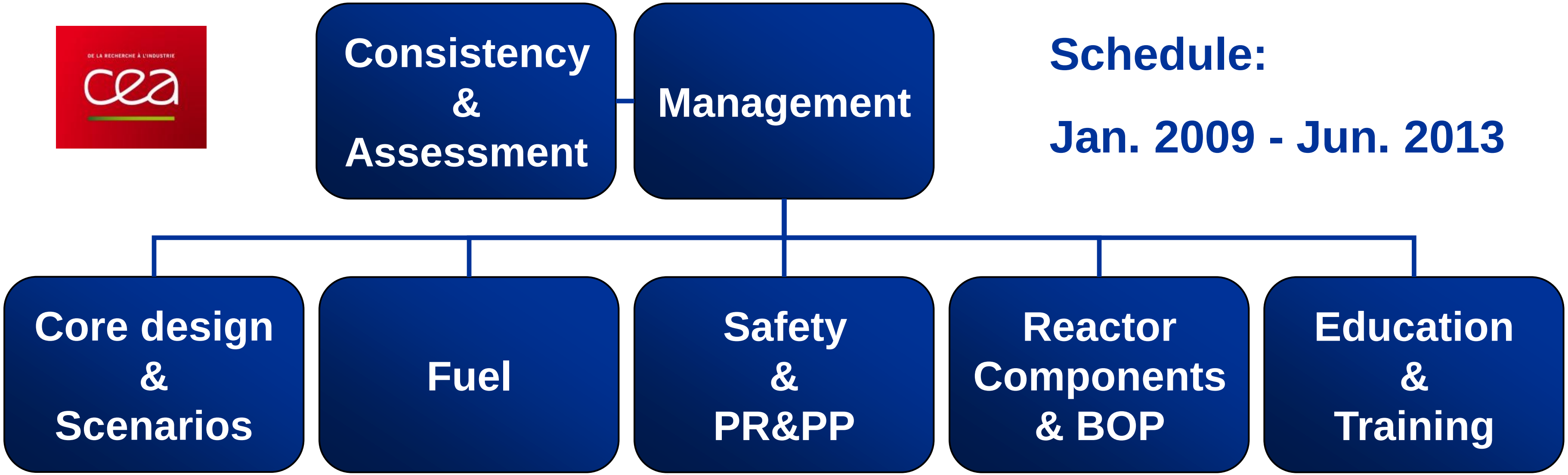
EMPRESARIOS AGRUPADOS

ENEA

KIT
Karlsruhe Institute of Technology

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

cea



Consistency & Assessment — **Management**

- **Core design & Scenarios**
- **Fuel**
- **Safety & PR&PP**
- **Reactor Components & BOP**
- **Education & Training**

Schedule:

Jan. 2009 - Jun. 2013

JRC
EUROPEAN COMMISSION

NRG

ÚJV

PAUL SCHERRER INSTITUT
PSI

SENER

SAPIENZA
UNIVERSITÀ DI ROMA

itu
Institute for Transuranium Elements

ipsc
Institute for the Protection and Security of the Citizen

ie
Institute for Energy

POLITÉCNICA

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

ENSA
Equipos Nucleares, S.A.

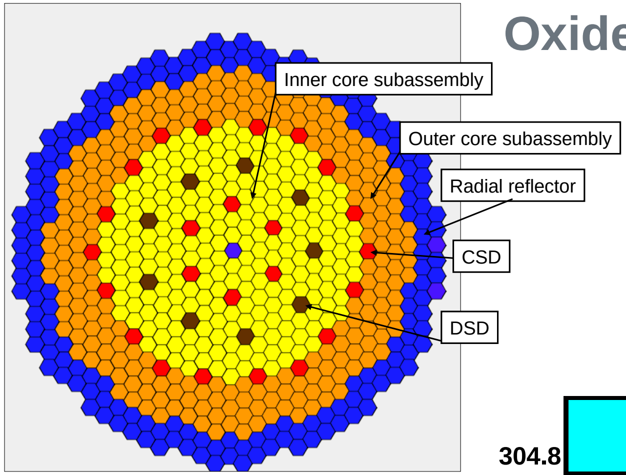
acciona
Infraestructuras

University of Latvia
Institute of Physics

CP ESFR Core studies

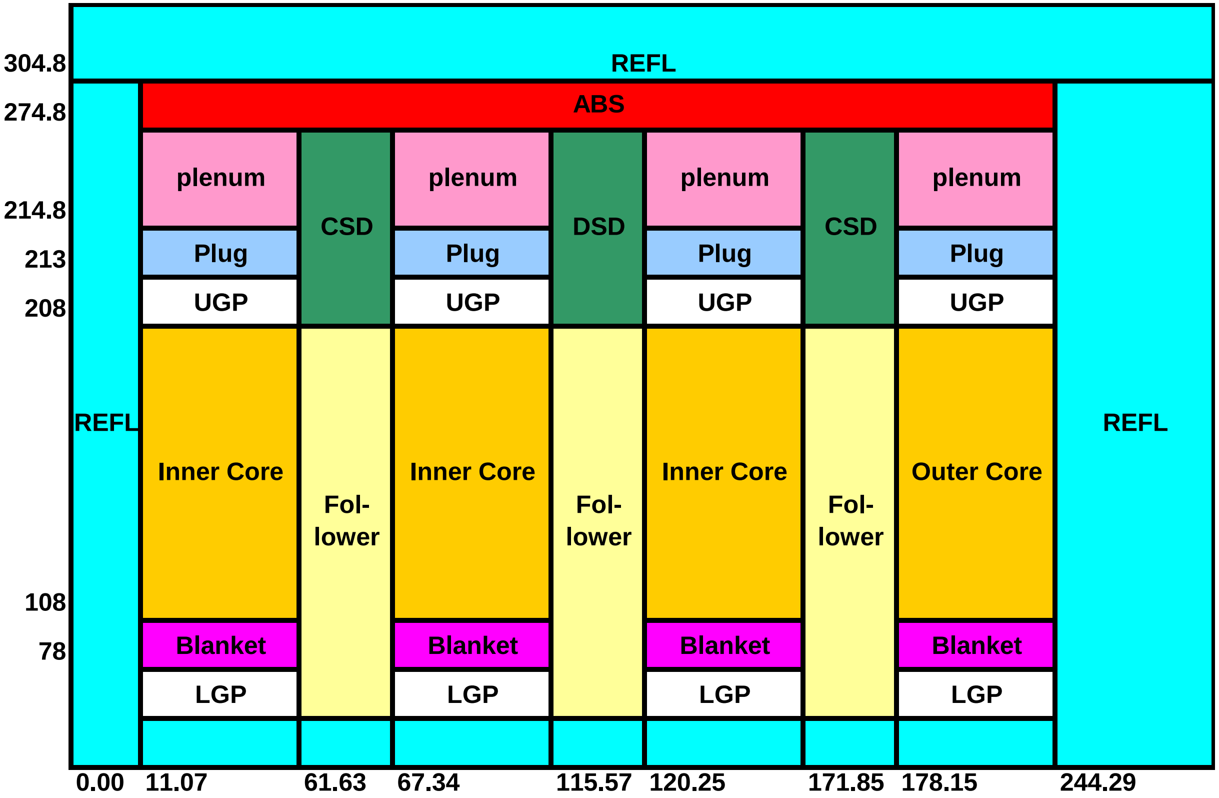
- **First phase (2 years) based on “Working horse” oxide and carbide cores.**
- **Second phase (2 years) devoted to the optimization and MAs transmutation performances.**
- **Safety improvements**
  - Reduction of sodium void worth
  - Reduction of reactivity loss during fuel irradiation to limit control rod withdrawal effects.
  - Limited impact of MAs loading

CP ESFR Core studies



Oxide working horse core.

Optimized oxide core.



CP ESFR Core studies

Equilibrium open cycle core parameters

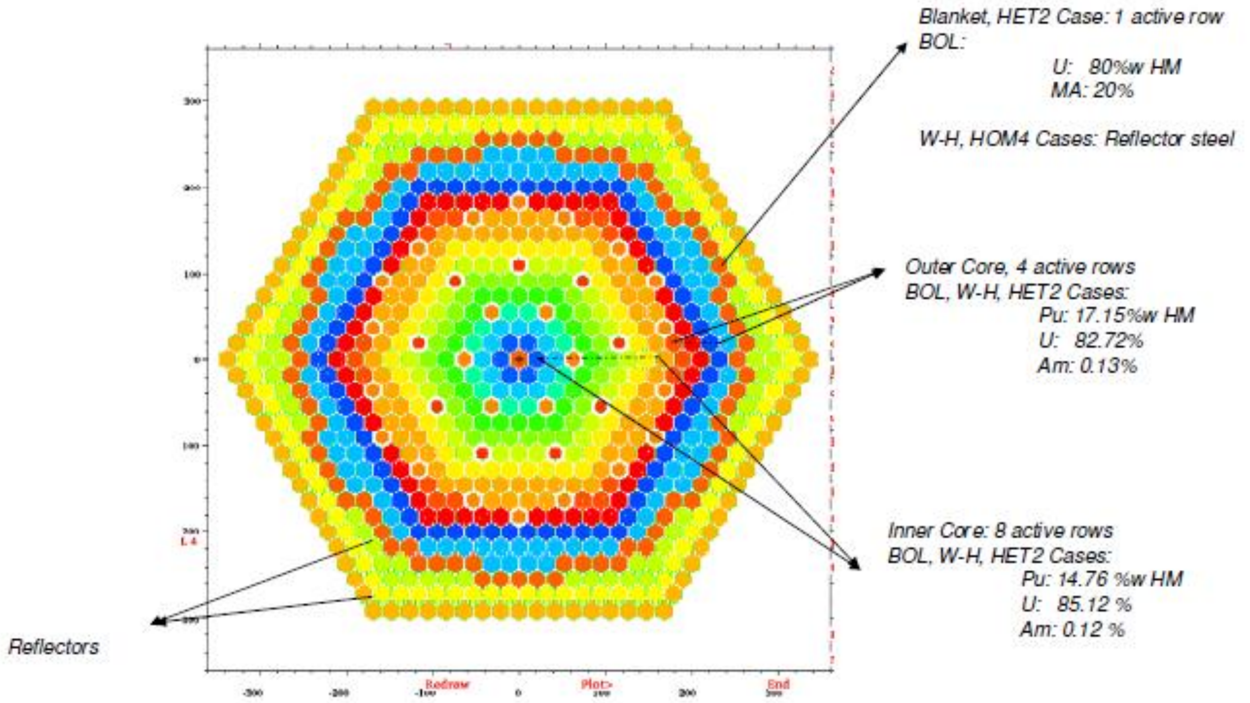
	BOL	BOC	EOC
Core reloading pattern		**One-batch**	**One-batch**
Equivalent burn up position (EFPD)	**0**	**820**	**1230**
K_{eff}	1.01201	1.01197	1.01043
Reactivity (PCM)	1187	1183	1032
Breeding gain	0.196	0.143	0.120
$^{239}Pu/^{238}U$ mass ratio	0.066	0.081	0.087
Void ρ in AC and plenum (PCM)	512	884	1017
Doppler const. (PCM)	-1169	-1020	-959
Void ρ in AC and plenum at Dopp. temp. (PCM)	638	991	1116
Doppler const. by voided AC and plenum (PCM)	-921	-810	-764
β_{eff} (JEF 2.2) (PCM)	393	372	364
Λ (JEF 2.2) (μs)	0.446	0.418	0.409
β_{eff} (JEFF 3.1) (PCM)	401	380	372
Λ (JEFF 3.1) (μs)	0.446	0.418	0.409
Diagrid expansion (PCM/°C)	-0.847	-0.834	-0.834
Fuel expansion (PCM/°C)	-0.153	-0.141	-0.142
Cladding & wrapper expansion (PCM/°C)	0.137	0.168	0.178
Global coolant expansion (PCM/°C)	0.145	0.304	0.362
Global coolant expansion (PCM/g/cm^3)	602	1260	1498

Minor Actinides transmutation

Two options studied:

- **Low transmutation rate (HET2 option)**
  Transmutation of self producing MAs loaded in 84 radial blanket S/As
  20% MAs – 80% Depleted U
  Small impact on safety coefficients

- **High transmutation rate (HOM4 option)**
  Fuel loaded with 4% MAs homogeneously
  Stronger impact on safety coefficients at BOL, smaller at BOC



Blanket, HET2 Case: 1 active row
BOL:
U: 80%w HM
MA: 20%

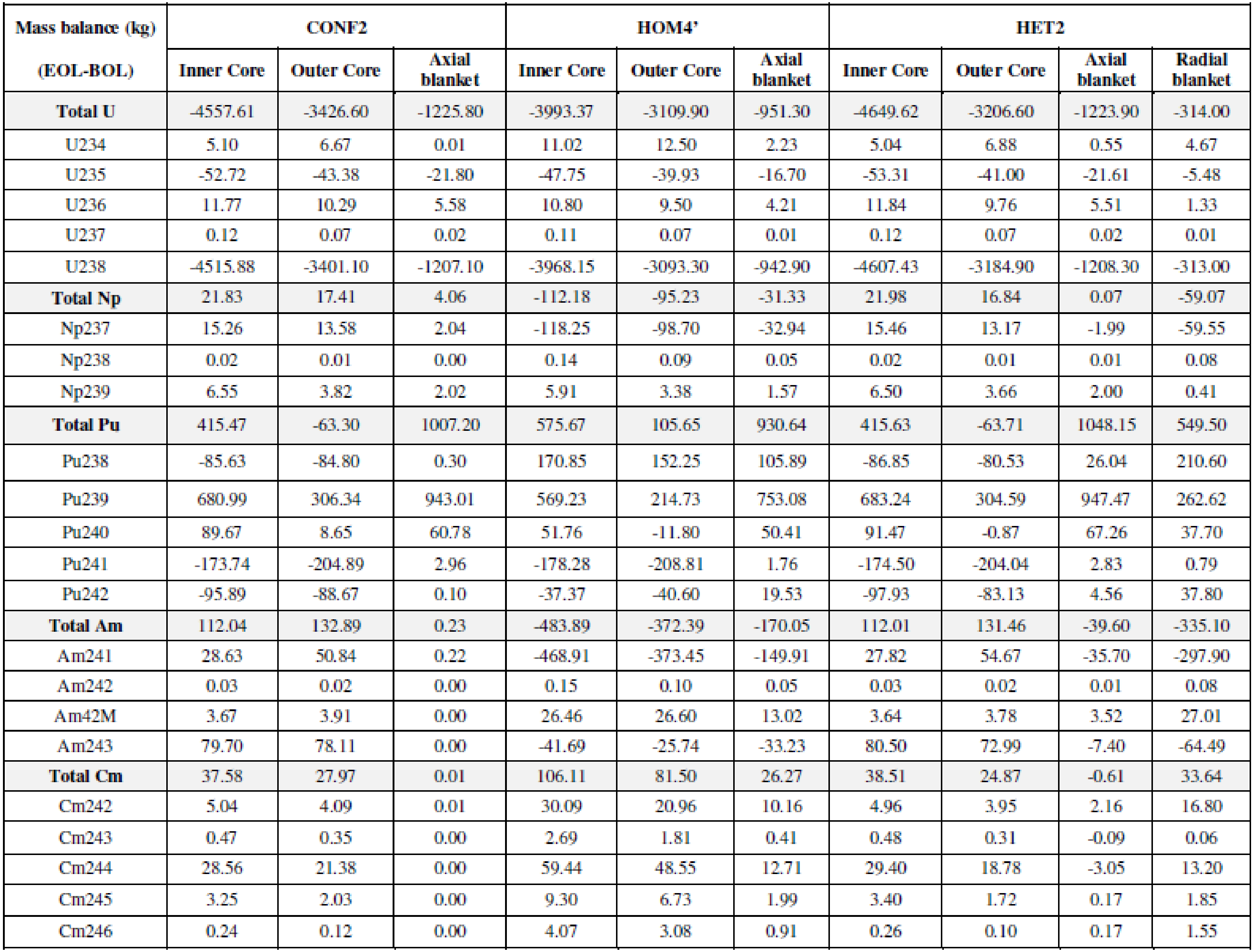
W-H, HOM4 Cases: Reflector steel

Outer Core, 4 active rows
BOL, W-H, HET2 Cases:
Pu: 17.15%w HM
U: 82.72%
Am: 0.13%

Inner Core: 8 active rows
BOL, W-H, HET2 Cases:
Pu: 14.76 %w HM
U: 85.12 %
Am: 0.12 %

Reflectors

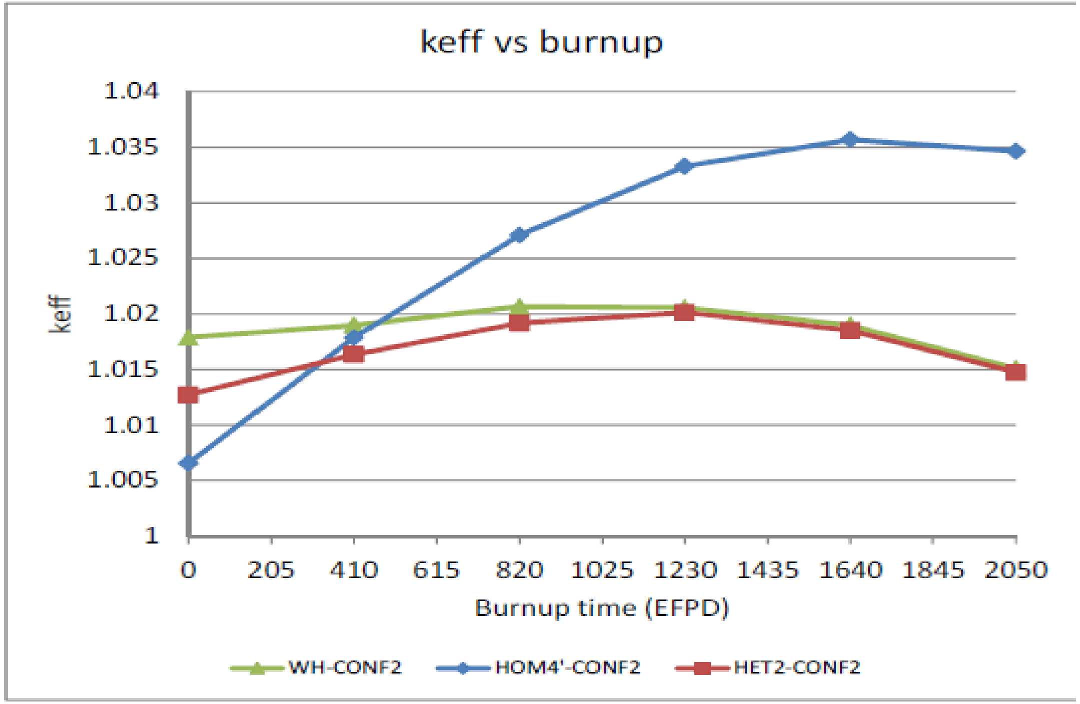
Mass balances per isotope



Mass balance (kg) (EOL-BOL)	CONF2			HOM4'			HET2			
	Inner Core	Outer Core	Axial blanket	Inner Core	Outer Core	Axial blanket	Inner Core	Outer Core	Axial blanket	Radial blanket
Total U	-4557.61	-3426.60	-1225.80	-3993.37	-3109.90	-951.30	-4649.62	-3206.60	-1223.90	-314.00
U234	5.10	6.67	0.01	11.02	12.50	2.23	5.04	6.88	0.55	4.67
U235	-52.72	-43.38	-21.80	-47.75	-39.93	-16.70	-53.31	-41.00	-21.61	-5.48
U236	11.77	10.29	5.58	10.80	9.50	4.21	11.84	9.76	5.51	1.33
U237	0.12	0.07	0.02	0.11	0.07	0.01	0.12	0.07	0.02	0.01
U238	-4515.88	-3401.10	-1207.10	-3968.15	-3093.30	-942.90	-4607.43	-3184.90	-1208.30	-313.00
Total Np	21.83	17.41	4.06	-112.18	-95.23	-31.33	21.98	16.84	0.07	-59.07
Np237	15.26	13.58	2.04	-118.25	-98.70	-32.94	15.46	13.17	-1.99	-59.55
Np238	0.02	0.01	0.00	0.14	0.09	0.05	0.02	0.01	0.01	0.08
Np239	6.55	3.82	2.02	5.91	3.38	1.57	6.50	3.66	2.00	0.41
Total Pu	415.47	-63.30	1007.20	575.67	105.65	930.64	415.63	-63.71	1048.15	549.50
Pu238	-85.63	-84.80	0.30	170.85	152.25	105.89	-86.85	-80.53	26.04	210.60
Pu239	680.99	306.34	943.01	569.23	214.73	753.08	683.24	304.59	947.47	262.62
Pu240	89.67	8.65	60.78	51.76	-11.80	50.41	91.47	-0.87	67.26	37.70
Pu241	-173.74	-204.89	2.96	-178.28	-208.81	1.76	-174.50	-204.04	2.83	0.79
Pu242	-95.89	-88.67	0.10	-37.37	-40.60	19.53	-97.93	-83.13	4.56	37.80
Total Am	112.04	132.89	0.23	-483.89	-372.39	-170.05	112.01	131.46	-39.60	-335.10
Am241	28.63	50.84	0.22	-468.91	-373.45	-149.91	27.82	54.67	-35.70	-297.90
Am242	0.03	0.02	0.00	0.15	0.10	0.05	0.03	0.02	0.01	0.08
Am42M	3.67	3.91	0.00	26.46	26.60	13.02	3.64	3.78	3.52	27.01
Am243	79.70	78.11	0.00	-41.69	-25.74	-33.23	80.50	72.99	-7.40	-64.49
Total Cm	37.58	27.97	0.01	106.11	81.50	26.27	38.51	24.87	-0.61	33.64
Cm242	5.04	4.09	0.01	30.09	20.96	10.16	4.96	3.95	2.16	16.80
Cm243	0.47	0.35	0.00	2.69	1.81	0.41	0.48	0.31	-0.09	0.06
Cm244	28.56	21.38	0.00	59.44	48.55	12.71	29.40	18.78	-3.05	13.20
Cm245	3.25	2.03	0.00	9.30	6.73	1.99	3.40	1.72	0.17	1.85
Cm246	0.24	0.12	0.00	4.07	3.08	0.91	0.26	0.10	0.17	1.55

Impact of Minor Actinides loading on reactivity coefficients

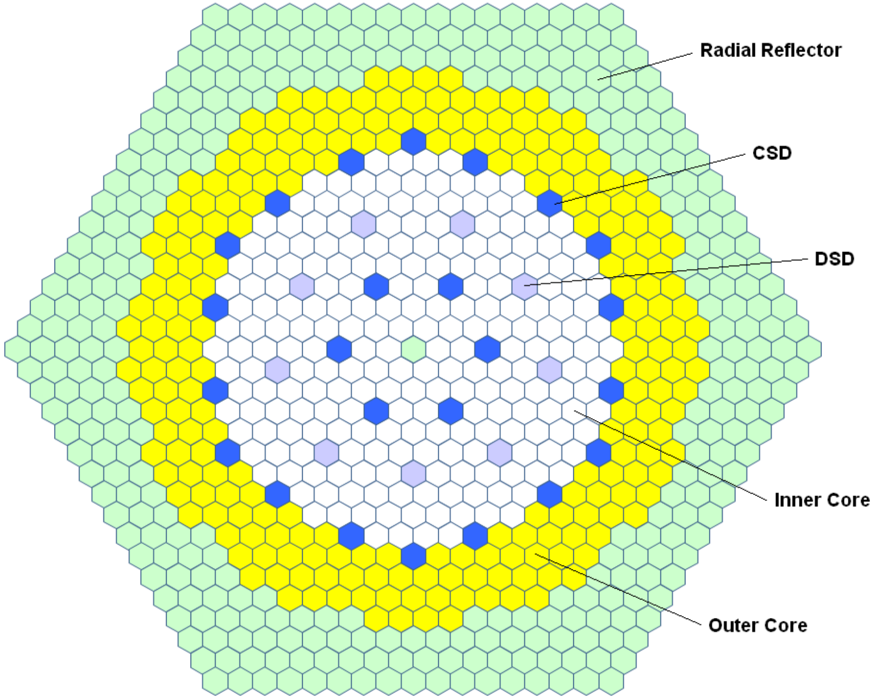
	CONF2		HOM4'		HET2	
	BOC	EOC	BOC	EOC	BOC	EOC
Doppler (pcm)	-827	-772	-594	-629	-783	-717
βeff	370	362	346	338	368	359
Core void worth (pcm)	1516	1654	1712	1746	1517	1626
Core void worth ($)	4.10	4.57	4.95	5.17	4.12	4.53
Reactor void worth (pcm)	767	922	1061	1095	743	875
Reactor void worth ($)	2.07	2.55	3.07	3.24	2.02	2.44



Carbide core

	Working Horse Core	Optimised Core
Number of Inner core S/A	168	225
Number of Outer Core S/A	246	228
Number of CSD	24	24
Number of DSD	12	9
Active Core Height (m)	0.8	1.0
SA Pitch (mm)	183.2	176.3
Sodium gap width inter assembly (mm)	4.5	4.5
Wrapper tube outer flat-flat width (mm)	178.7	171.8
Wrapper tube thickness (mm)	4.5	4.5
Wrapper tube material	FM Steel (EM10)	FM Steel (EM10)
Wire wrap spacer diameter (mm)	1	1
Wire wrap helical pitch (mm)	225	225
Wire wrap spacer material	ODS Steel	ODS Steel
Number of fuel pins per sub-assembly	331	271
Outer clad diameter (mm)	8.0	8.5
Inner clad diameter (mm)	7.0	7.5
Cladding material	ODS Steel	ODS Steel
Fuel pellet diameter (mm)	6.87	7.37
Fuel pellet material	(U, Pu)C	(U, Pu)C
Inner Core Fuel Enrichment (atom%)	17.8	14.05(1)
Outer Core Fuel Enrichment (atom%)	24.5	18.35(1)

Carbide core



- Significant changes for optimization
  - Lower fuel enrichment than oxide
  - Smaller pin diameter and S/A pitch
- Close to oxide (but not so good) on sodium void coefficient
- DSD control rod worth higher than oxide

Conclusions (1/2)

- Significant progress has been made in optimizing both the oxide and carbide ESFR cores
- For the oxide core the optimisation process concentrated on the reduction of the sodium void reactivity effect and on the evaluation of MA burning performances. The CONF2 axial configuration has provided a significant overall reduction of the sodium void reactivity effect.
- The carbide core had a significantly higher reactivity loss over the fuel cycle compared to the oxide one. By increasing slightly the fuel pin diameter, whilst still retaining the advantages of lower fuel temperatures of carbide fuel, and making changes in the core layout, the reactivity loss over the cycle has been reduced to a level similar to that of the oxide core. By adopting the CONF2 axial configuration initially developed for the oxide core, the sodium void reactivity of the carbide core has also been reduced appreciably.

Conclusions (2/2)

- The MA transmutation performances of the optimized ESFR oxide core have been investigated with respect to two boundary configurations. The HET2 configuration shows a low MA transmutation rate sufficient to burn the MA produced by the ESFR core without affecting the safety parameters. The HOM4 configuration (where 4%wt. MA are loaded homogeneously in each core SA) is the most challenging configuration due to its impact on safety coefficients but it shows an high MA burning rate suitable for burning also MA accumulated by a thermal reactor fleet.