Analyses of Transients for 400MWth-Class EFIT Accelerator Driven Transmuter with the SIMMER-III Code

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Introduction: ADS (XT-ADS, EFIT)

IP EUROTRANS

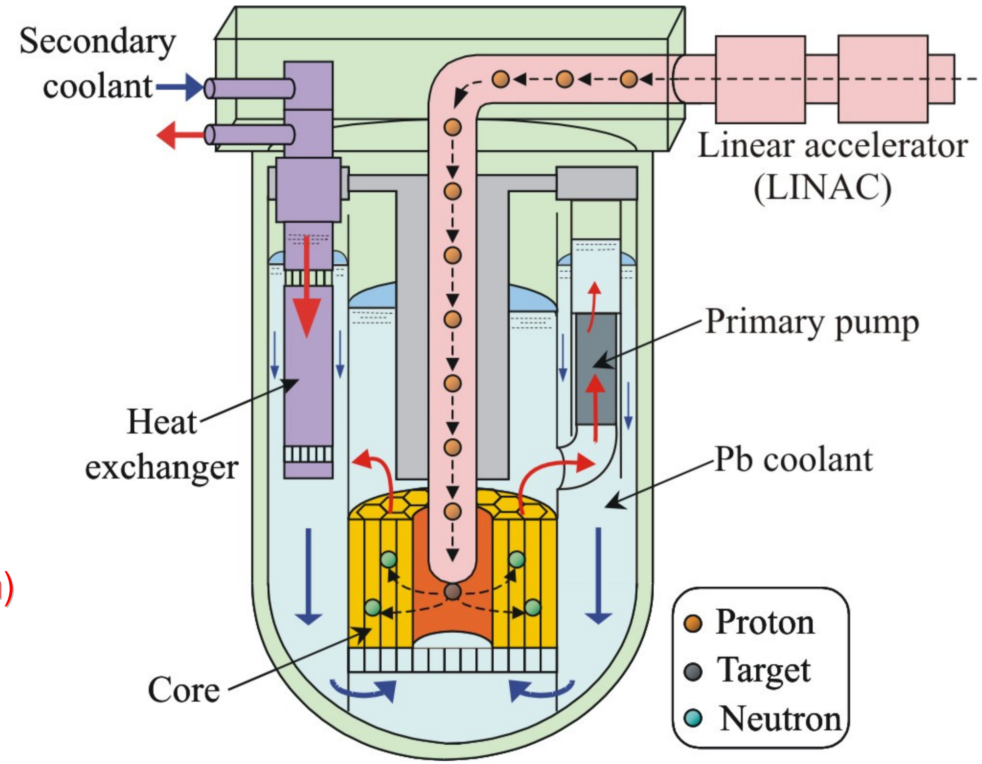
Transmutation of Minor Actinides (MAs) with ADS (XT-ADS, EFIT)

XT-ADS

- Less than 100 MWth;
- Short-term
  - Demonstration of ADS feasibilty,
  - Demostration of transmutation
  - Core with MOX fuel
  - Irradiation facility

EFIT (European Facility for Industrial Transmutation)

- About 400 MWth;
- Long term
  - Transmutaion in industrial scale;
  - Core with dedicated fuel: high MA content

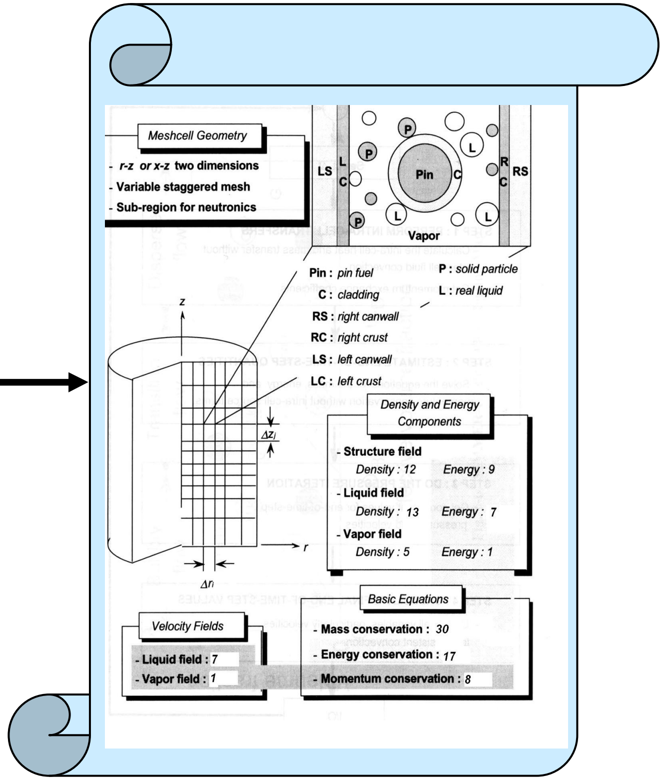


Introduction: SIMMER code

ADS, LMFR
LWR

Steady-state
Transients

SIMMER-III/IV



Fluid Dynamics

- 8 velocity fields (7 for liquid, 1 for gas)
- Multi-phase, multi-component flow
- Phase transitions
- Flow regime (pool-channel)
- Interfacial area tracking
- Elaborate EOS (fuels, structure, coolants & gases)
- Heat and mass and momentum transfer

Structure model

- General structure model
- Pin model (new fuels - development)
- Axial + radial heat transfer
- Virtual structure model
- Structure disintegration
- Freezing on structures

Neutronics

- Neutron transport theory (S_n)
- Improved quasi-static method
- Cross-section generation
- Decay heating
- External neutron source
- Transient source importance

Neutronics assumptions

- Beginning of Life conditions
- 11-group cross-sections below 20 MeV, including f-factors, homogeneous S/A model
- Spallation source as external neutron source:
  - Spectrum: time-independent, high energy neutrons put in the 1st energy group
  - Amplitude: normalized to get the known reactor power at nominal conditions, time-dependence specified by the user

3-Zone EFIT core design (1)

Fuel: CERCER (Pu, Am, Cm)O2-x – MgO;

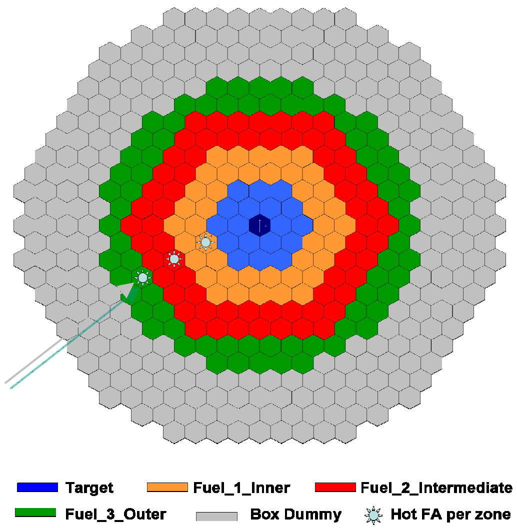
42-0 approach:

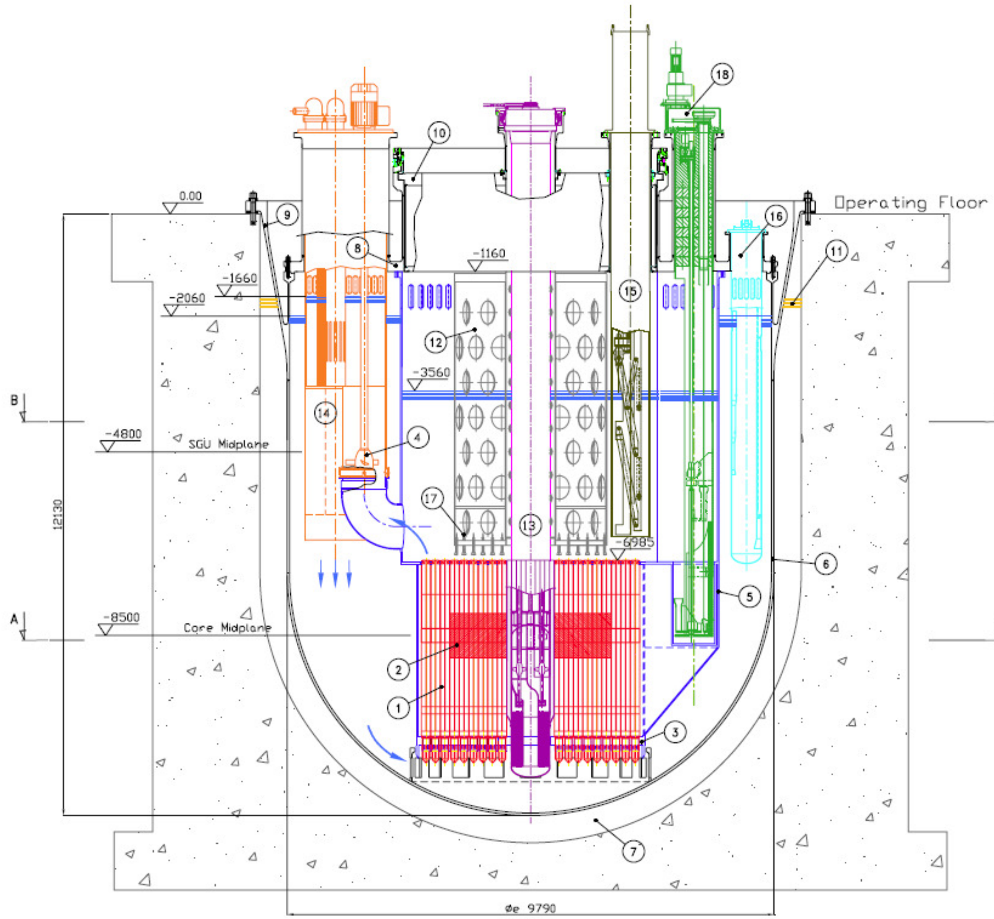
Burns 42/0 kg of MAs/Pu per TWh (th);

Initial Pu/Ma content 45.7/54.3 wt%;

3-Zone: 42 FA (inner), 66 FA (middle), 72 FA (outer)

6 hottest FA in each zone due to symmetry





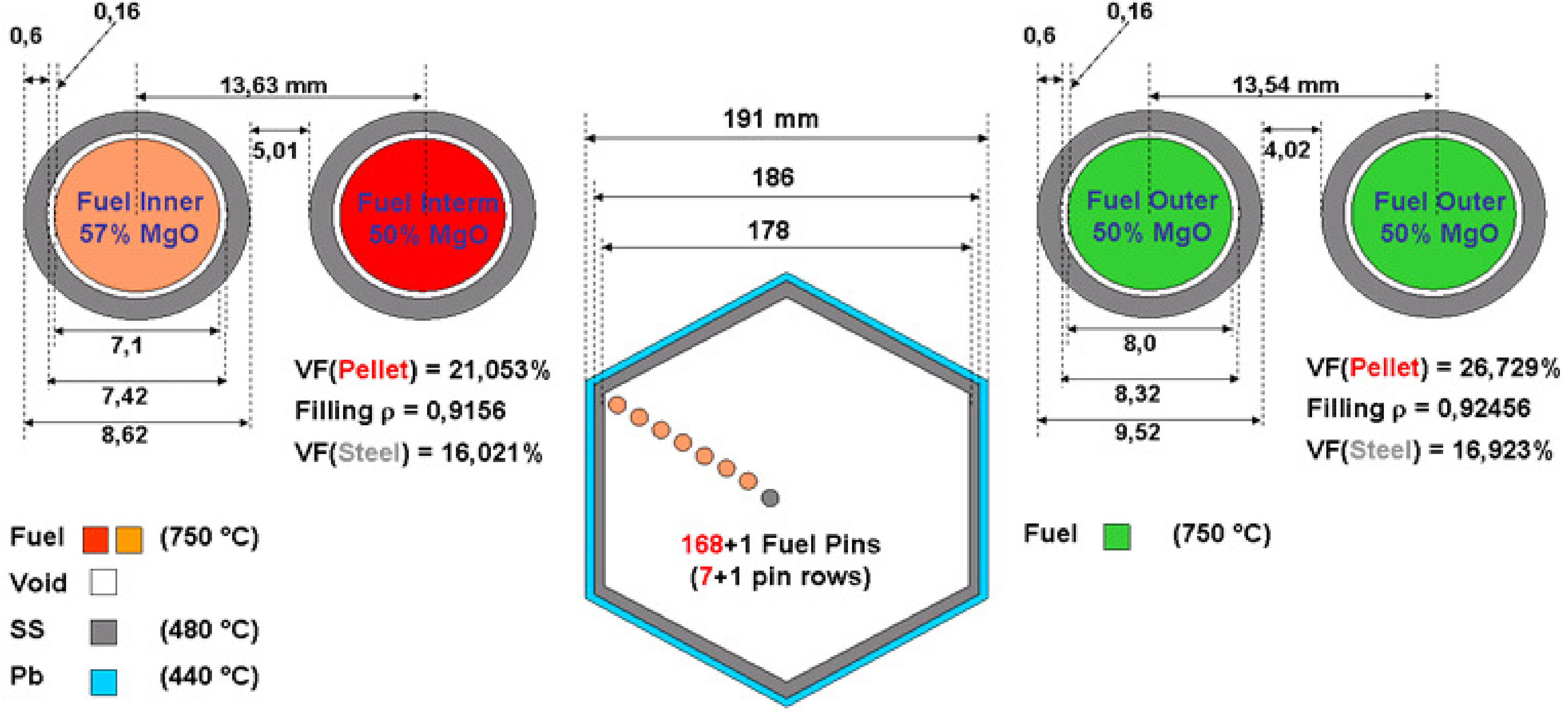
Power = 384 MWth; Pool type reactor with hot leg pump;

Coolant: Pb, T-in /T-out = 400/480 ^{o}C;

Fuel: MgO-CERCER (IP EUROTRANS DM1) or Mo-CERMET (DM3);

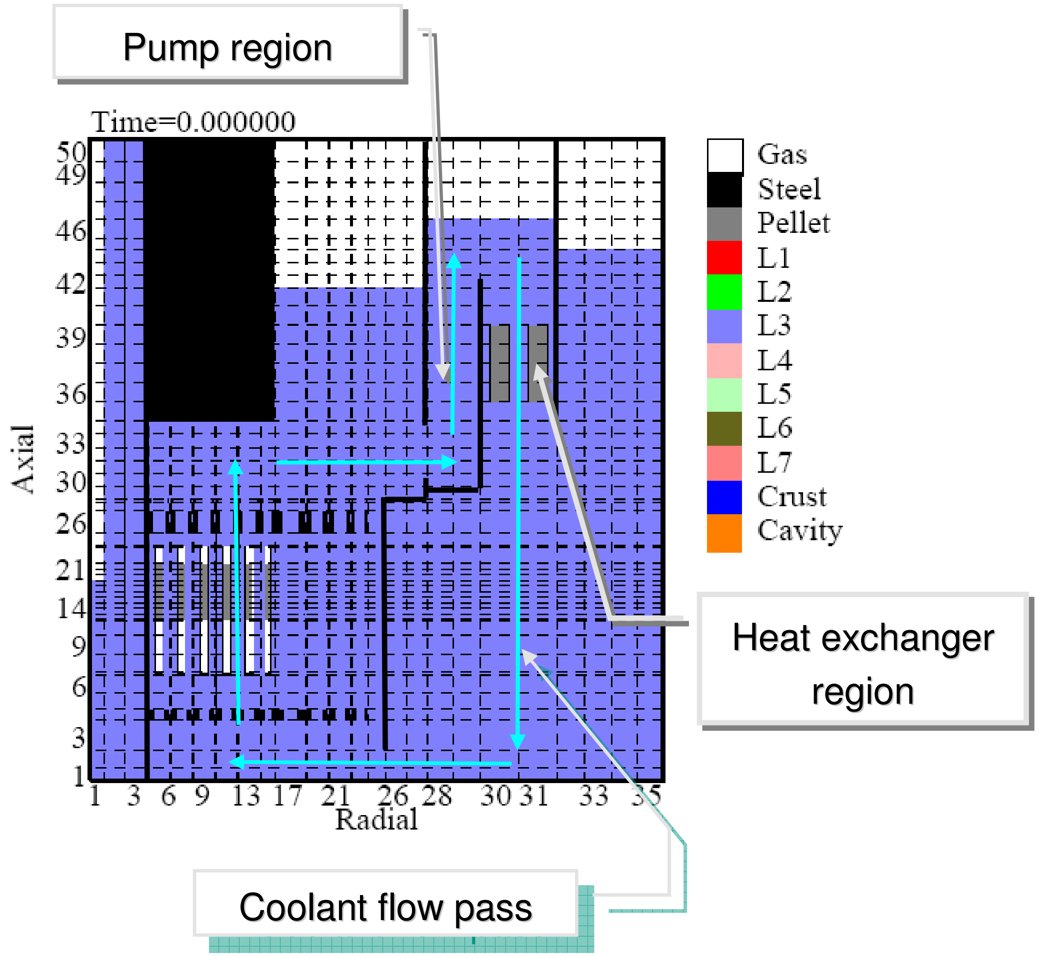
Clad: T91;

3-Zone EFIT core design (2)



Fuel pin and FA geometry in the different core zones.

SIMMER-III model of EFIT

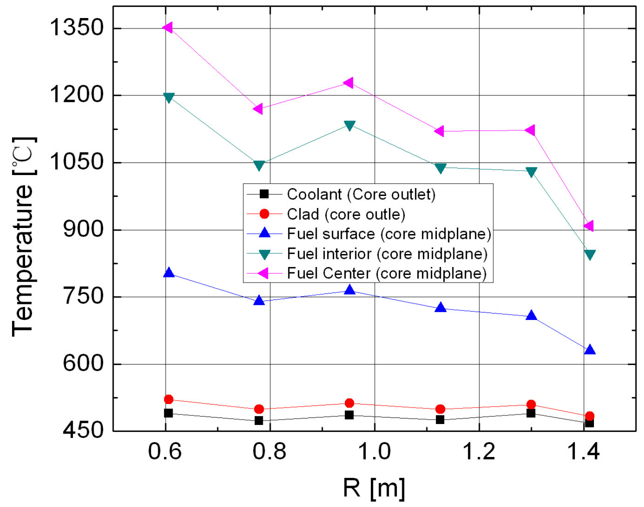


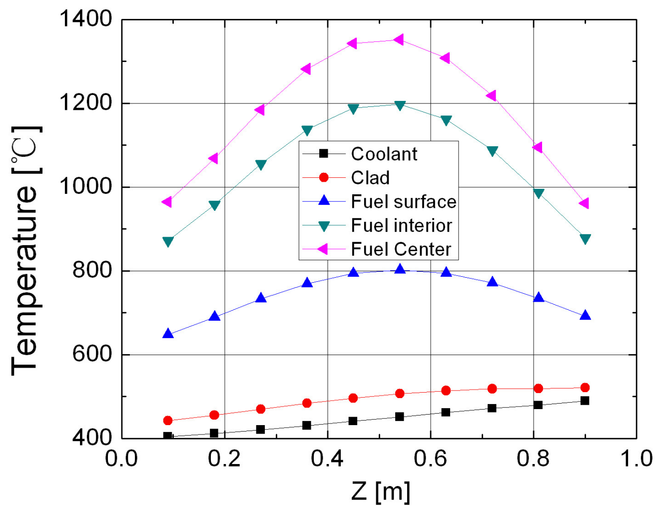
Steady state analysis of the 3-zone core (1)

COMPARISON OF STEADY-STATE PARAMETERS.

Parameter		Inner zone	Middle zone	Outer zone	Reflector-dummy + by-pass	Total
Nominal temperature	°C	400°C (inlet), 480°C (outlet)			-	
Power (SIMMER-III)	MW	94.65	143.26	142.57	-	380.48
Power (ENEA Design)	MW	95.98	142.31	140.48	-	378.77
Pb mass flow rate (SIMMER-III)	kg/s	7854.1	12248.7	12036.8	1176.5	33326.1
β-eff	pcm	159 (SIMMER-III), 148 (MCNPX)				
Whole active-core void worth	pcm	7169 (SIMMER-III), 6670 (MCNPX)				
Doppler constant	-	near zero (SIMMER-III and ERANOS)				
K-eff	-	0.975 (SIMMER-III)				

Steady state analysis of the 3-zone core (2)





SIMMER-III Calculated

Peak Fuel Temperature: 1352.1 °C; Peak Clad Temperature: 521.1 °C.

Limit temperatures at nominal conditions: Fuel 1380 °C, Clad 550 °C;

EFIT core safety criteria for fuel and clad

Fuel temp. limits

			MgO CERCER	Mo92 CERMET
"Melting" temperature		Matrix	2150 K*	2896 K
		Fuel	2450 K	2450 K
DBC	Category I	No melting/disintegration	1750 K	2300 K
	Category II	No melting/disintegration	1850 K	2350 K
	Category III	No melting/disintegration	1950 K	2400 K
	Category IV	No 'melting' for CERCER and CERMET fuels	1950 K	2400 K
DEC		Limited up to extended 'melting'	2150 K	2450 K

* Matrix evaporation limit

Creep failure temperature limits for T91 steel

Pressure in the plenum	**Temperature limits at corresponding failure time [°C]**					
	0.1 s	1 s	10 s	2 min	30 min	10 hour
10 bar	1069	1007	950	894	838	783
50 bar	1042	981	925	870	815	761
100 bar	1009	949	894	841	788	735

- Defence-in-Depth concept applied for safety;
- Safety objectives structured along three basic conditions: DBC, DEC, Residual Risk situation;
- For DBC and DEC, restrictive limit taken due to uncertainties in the fuel data obtain so far.
- Natural convection to remove the decay heat;

Summary of transient cases (1)

DEFINITION OF ANALYZED TRANSIENTS

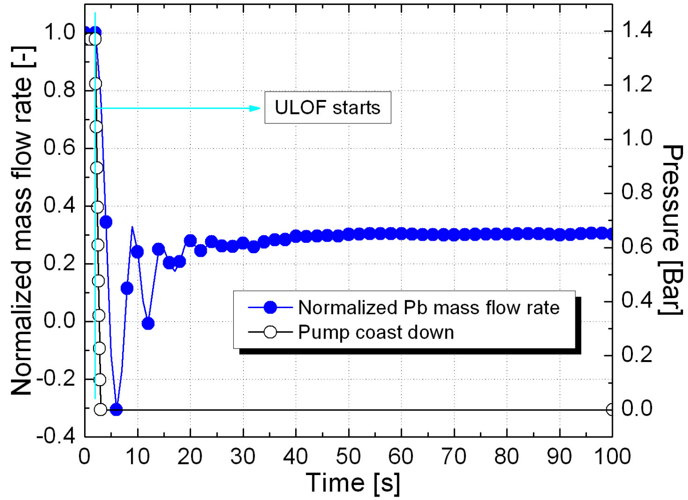
Transient No.	Transient cases	Descriptions	Burn-up state
P-1	PLOF	Source-off after 3 sec of the start of LOF, Pump stops within 1 sec	BOL
P-2	PTOP	500 pcm jump in reactivity, Source-off after 3 sec of the starts of over power	BOL
P-9	Protected blockage with radial heat transfer (PBA)	Source-off after 3 sec. of start of blockage, flow rate of peak FA-ring reduced to less than 10%	BOL
P-10	Spurious beam trips (BT)	Beam trips for 1 and 10 sec intervals	BOL
U-1	ULOF	Complete loss of all forced/enhanced circulations in primary system, pump stops within 1 sec	BOL
U-2	UTOP	500 pcm jump in reactivity	BOL
U-9	Unprotected blockage with radial heat transfer (UBA)	Flow area of peak fuel assembly (FA) ring reduced to less than 10%	BOL
U-10	HX tube rupture	Steam generator tube rupture – 1 tube failure	BOL
U-11	Beam overpower	20% beam increase at hot full power	BOL

Summary of transient cases (2)

MAXIMAL TEMPERATURES IN CORRESPONDING TRANSIENT CASES

Transient cases	Clad maximal temp., °C	Fuel maximal temp., °C	Coolant maximal temp., °C
P-1, PLOF	690	1340	686
P-2, PTOP	524	1380	492
P-9, PBA	688	1364	679
P-10, 10s Beam trip	88 (Temp. decrease)	743 (Temp. decrease)	65 (Temp. decrease)
P-10, 1s Beam trip	14 (Temp. decrease)	129 (Temp. decrease)	10 (Temp. decrease)
U-1, ULOF	884 (Overshooting)	1687 (Overshooting)	858 (Overshooting)
	730 (Final stabilized)	1552 (Final stabilized)	685 (Final stabilized)
U-2, UTOP	538	1530	503
U-9, UBA	1430 (clad breaks up close to melting point)	Pin breaks up due to cladding lost	Few local coolant boiling happens
U-11, Beam overpower	545	1597	507

ULOF analysis

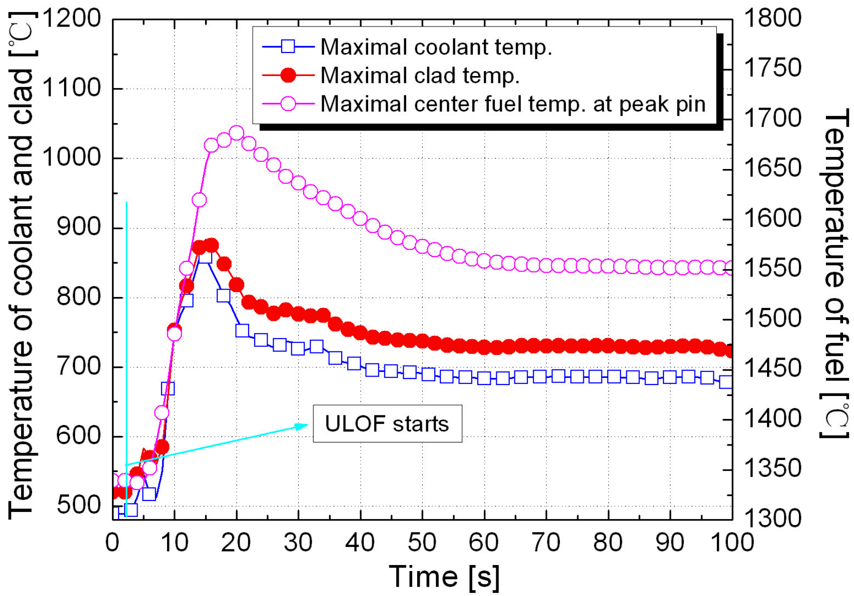


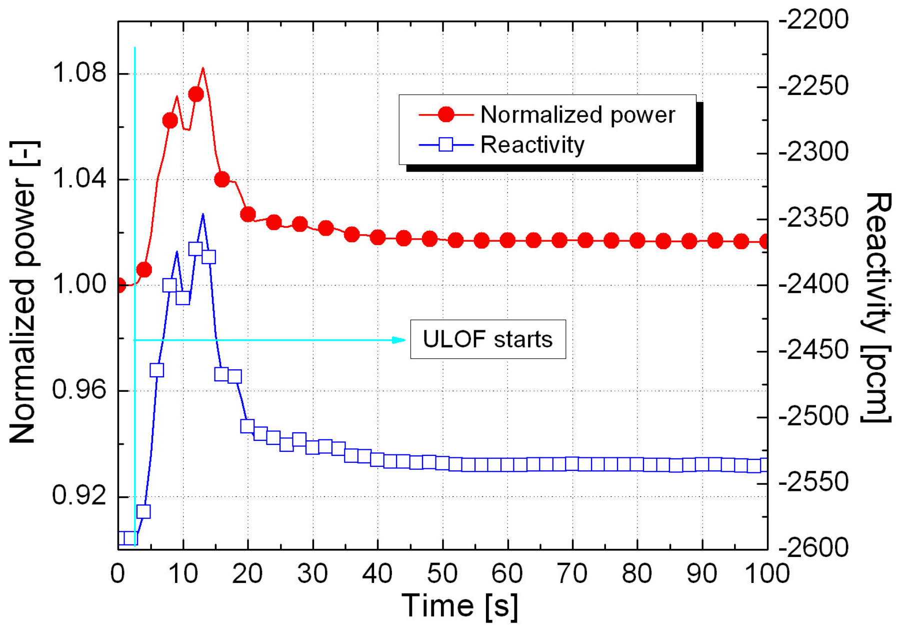
Assumptions and conditions:

Core - SG height difference 3.7 m; Total pressure drop in the primary system = 1.37 bar; Pump head becomes zero 1 s;

ULOF Summary:

- Under ULOF conditions, safety margins for both fuel and clad are respected because of the remained coolant flow due to natural convection despite the positive coolant feedback;
- Limitations on the cladding more responsible for reducing the flexibility in the ADT design.





Conclusions

- Several protected (beam-off) and unprotected (beam-on) transient scenarios have been analyzed for the EFIT core.
- Among all these scenarios, ULOF and UBA are the most severe transients.
- Under the current simulation conditions, except for the unprotected blockage case, the EFIT core can survive under all these transient conditions including the ULOF.
- UBA transients will lead to pin failures in the core. Because the knowledge of the blockage scenario is very limited and the material properties under high temperatures are not well established, further investigations need to be performed both experimentally and theoretically concerning the material behaviors in a high temperature range as well as the possible blockage phenomena themselves .