German SFR Research and European Sodium Fast Reactor Project

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with special thanks to E. Fridman, G. Gerbeth (FWD),
A. Vasile (CEA), W. Maschek (KIT)

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

JAEA-IAEA WS on "Prevention and Mitigation of Severe Accidents in SFRs“,
Tsuruga, June 12-13, 2012

Content

- The Situation in Germany

- Activities at HZDR
  - Liquid metal technologies
  - Enhanced feedback coefficients
  - Core simulator for SFR
  - German contribution to EBR-II benchmark

- Examples from KIT
  - SIMMER group
  - SAS group

- The ESFR project

The German Situation in Nuclear Research

Targets in the 6. Energy Research Program released August 2011:

- **Long-term and continuing well directed development**
- **Participation in international research projects and collaborations**
- **Nuclear expertise has be obtained on the basis of its own research**
- **Studies on the**
  - **Safety of planned new nuclear power plants in neighborhood**
  - **Potential of innovative reactor safety**
- **Participation in international activities on P&T**

Financial support:

- **Funding of 2010 will remain constant for at least 5 years**
- **Budget for nuclear in HGF centers constant until 2019/2020**

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Contactless Inductive Flow Tomography (CIFT)

A fully contactless technique to measure the 3D mean flow field in electrically conducting melt (analog Magnetoencephalographie in medicine)

- **Developed over past decade at HZDR:**

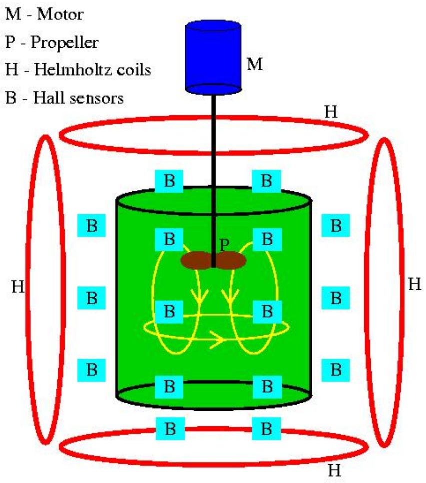
  Theory developed in 1999-2011

  Demo-experiment in 2003-2004

F. Stefani, G. Gerbeth, Inverse Problems 15, 771, 1999.
F. Stefani, G. Gerbeth, Meas. Sci. Techn. 11, 758, 2000.
F. Stefani, T. Gundrum, G. Gerbeth, Phys. Rev. E. 70, 056306, 2004.

- **Status: transfer to real problems in progress (steel casting, silicon crystal growth)**

T. Wondrak et al., Meas. Sci. Techn. 21, 045402, 2010.
T. Wondrak et al., Met. Mat. Transactions 42B, 1201, 2011.



- **A flow field modifies an external magnetic field:**

$$\mathbf{B} = \mathbf{B_0} + \mathbf{b}, \quad \mathbf{b} \sim R_m \mathbf{B_0} \quad (R_m = \mu\sigma L v)$$

$\Rightarrow$ **the magnetic field measured outside the melt contains information about the flow field**

- **Gives in a robust way the 3D mean flow field every ~ 1s**
- **Application in industrial silicon crystal growth:**

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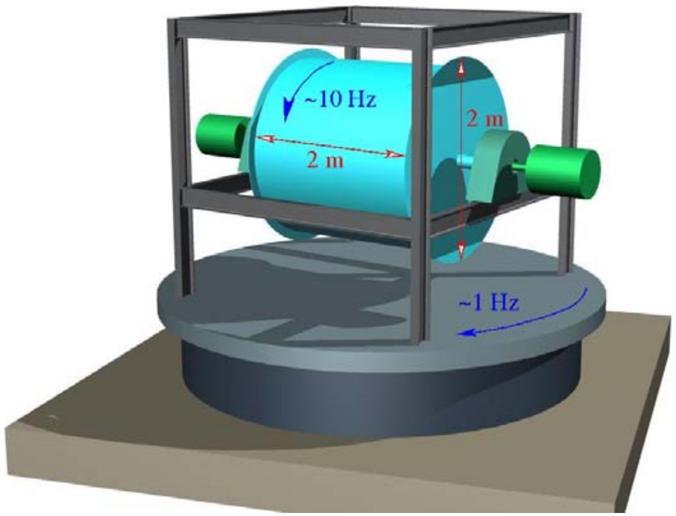
Project DRESDYN at HZDR

DRESDYN: A European platform for Dynamo-experiments and thermohydraulic studies with liquid sodium

Infrastructure project at HZDR (2012-2015), existing budget ca. 23 M€

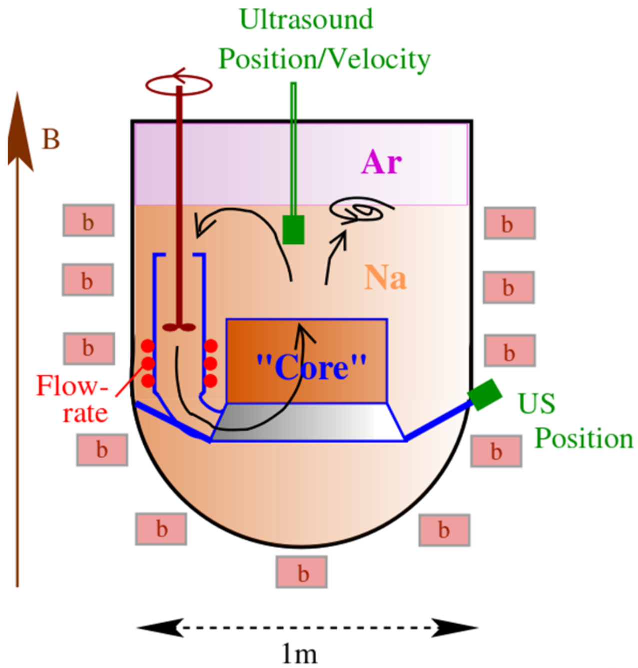
Precession driven Dynamo:

- 2 m diamter, 2 m height
  6.3 m^3 Na
- Rotation with 10 Hz
- Precession with 1 Hz
- Rm ~ 200

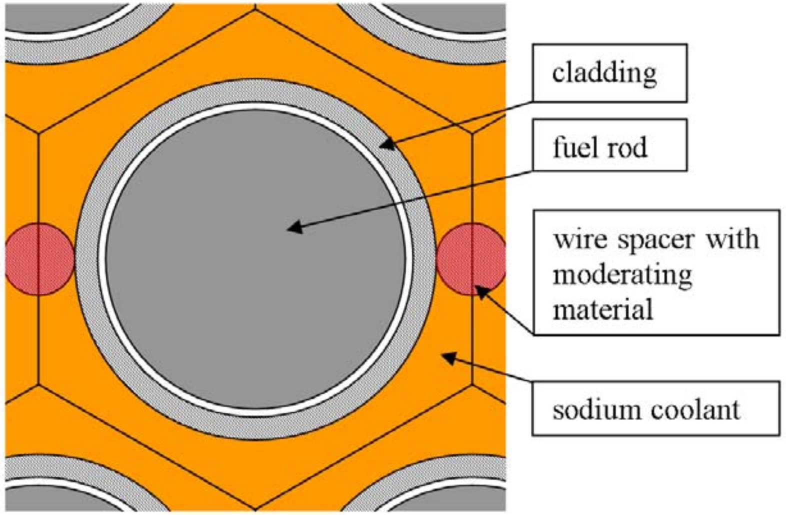


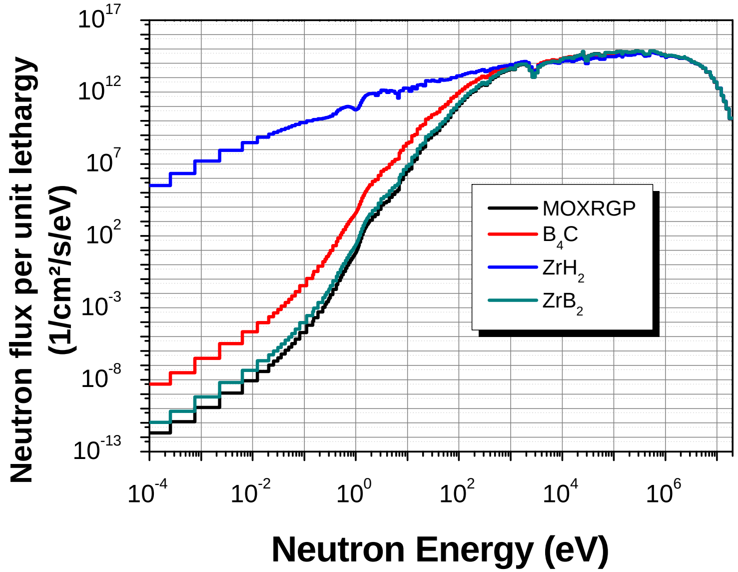
Na pool-type experiment for

- CIFT demonstration,
- flowrate and ultrasonic measurements
- bubble entrainment, bubble detection, etc.



Enhanced Feedback Coefficients





Insertion of fine distributed moderating material:

- **Hydrogen bearing metal compound**
- **Significant low energy tail formed in the spectrum**
- **Ideally located in the spacer wire**
- **ZrH or better YH for increased thermal stability**

Merk, Weiß, Annals of Nuclear Energy 38,5, (2011), 921-929
Merk, Weiß, Annals of Nuclear Energy 38,11 (2011) 2374–2385
Merk, Fridman, Kliem, Weiß, Nuclear Sci. and Eng. 171 (2012) 136-149

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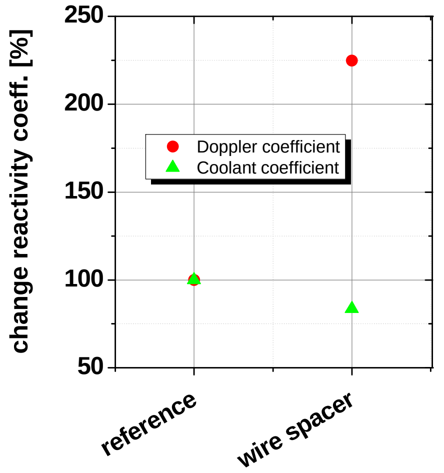
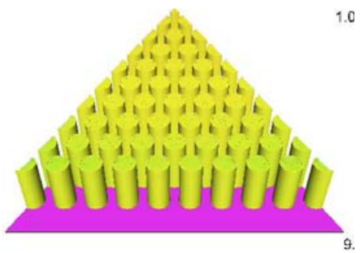
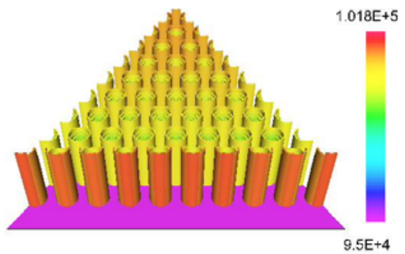
Enhanced Feedback Coefficients







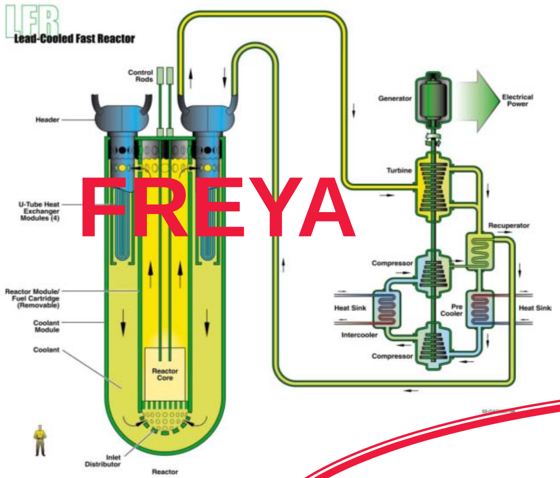
- Significant improvement of Doppler coefficient
- Reduction of positive coolant coefficient
- Strong reduction of sodium void effect
- Gain in sodium void is tranferable to full core

- loss in criticality
- slightly reduced breeding performance

- Conservation of fuel assembly geometry
- No hot spots like for moderation rods
- Uniform burnup distribution
- Nearly no influence on transmutation performance
- Possibility for compensation of MA influence on safety in transmutation cores

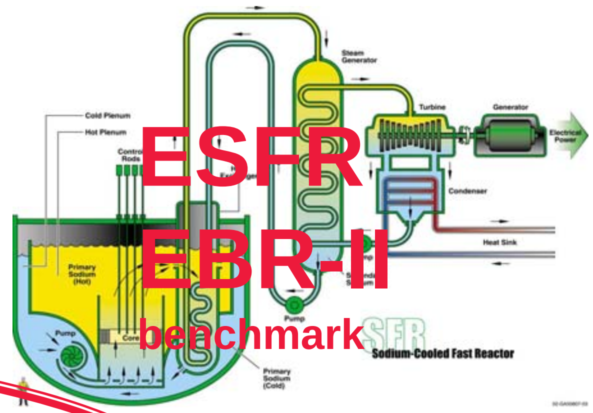
HZDR

Our Strategic DYN3D Project



FREYA

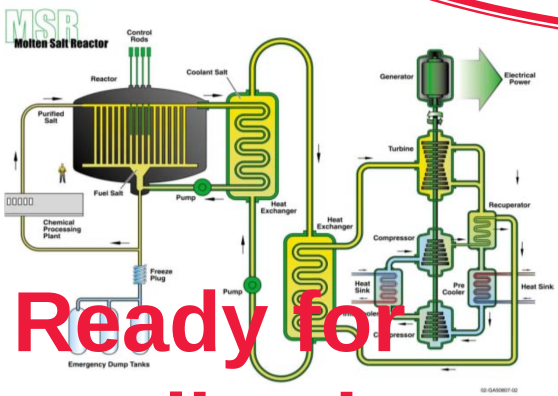
some extensions
for fast reactor
transients needed



ESFR
EBR-II
benchmark

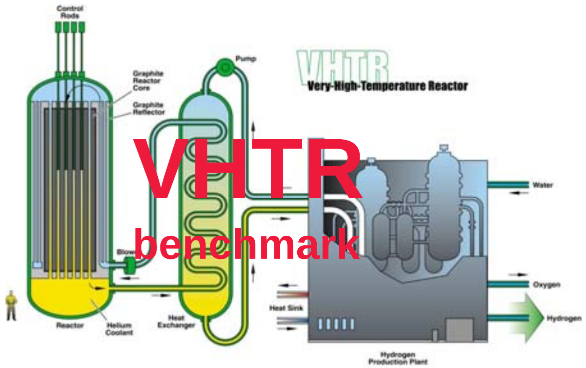
DYN3D

Tool for steady state and transient core calculations of GenIV reactor systems



Ready for application

ready to be validated
for steady state



VHTR
benchmark

coupling with
TRANSURANUS

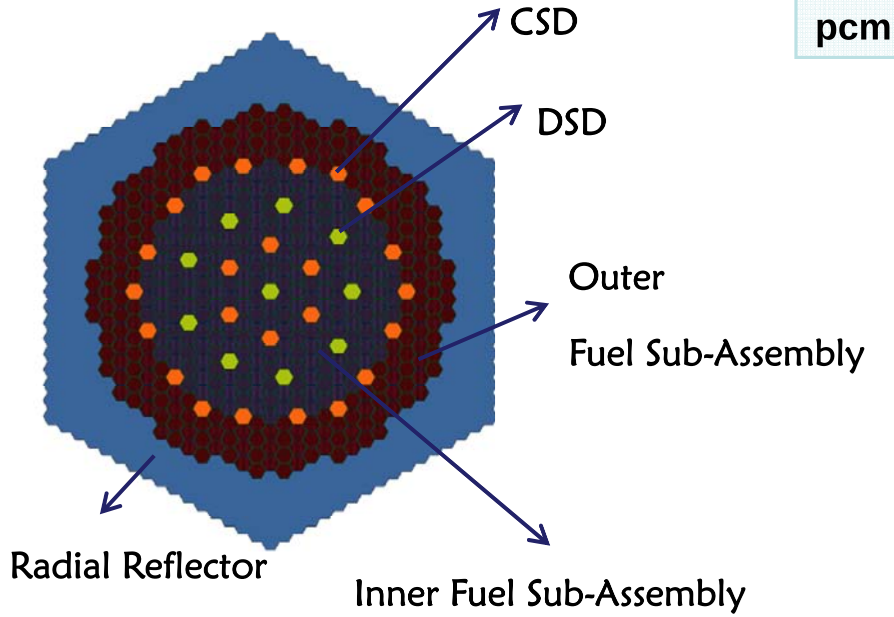
HZDR

SFR analysis approach (DYN3D validation program)

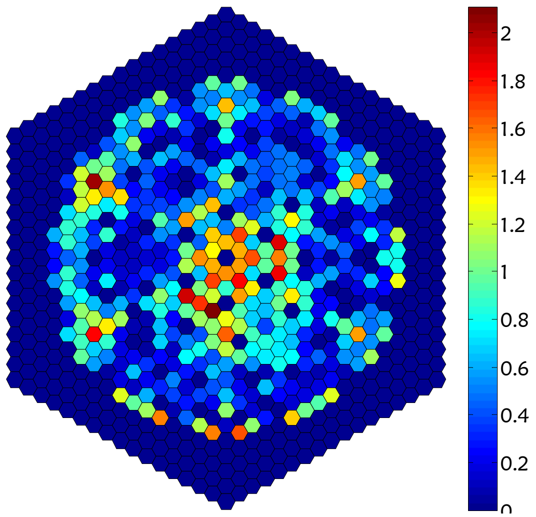
- **Create few-group XS with Serpent**
  - Monte-Carlo code neutron transport code
- **Use few-group XS in the DYN3D code**
  - 3D multi-group nodal diffusion code

Full core Monte-Carlo vs. DYN3D diffusion

	Serpent	DYN3D	Difference, Serpent vs. DYN3D
K-eff	1.11722	1.11674	38 pcm
CVR, pcm	2837	2816	21 pcm
k_D, pcm	-1154	-1147	7 pcm
CR worth, pcm	4678	4629	49 pcm



CSD = Control and Shutdown Device;
DSD = Diverse Shutdown Device



Relative difference in radial power , %

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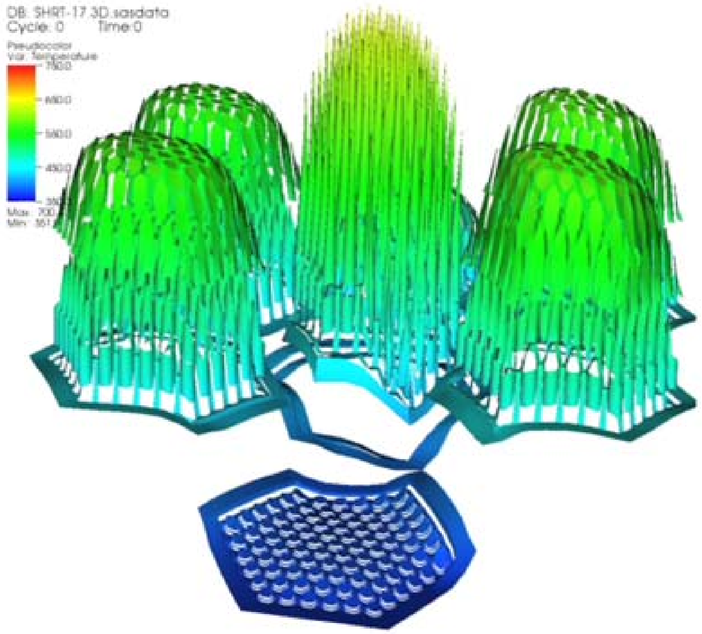
IAEA CRP on EBR-II Benchmark

SHRT-17: Transient Top-of-Core Coolant Temperatures in XX09 experimental subassembly

There will be two major contributions from Germany

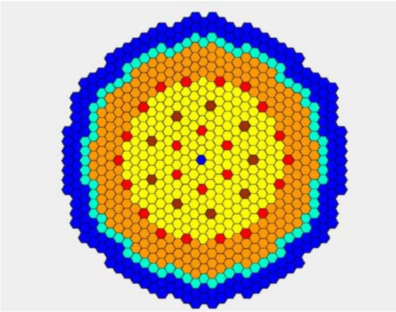
- from the SIMMER group
- a coordinated German contribution using updated LWR tools for coupled calculations
  - ATHLET – System code
  - DYN3D – Core simulator
  - SUBCHANFLOW – Subchannel analysis code



Mesh represents sodium temperature distribution over the XX09 inner assembly and surrounding assemblies (elevation and color represents temperature)

CP-ESFR (7th FP of EU) : Accident Prevention via Optimization of Safety Coefficients of CP-ESFR Core

Karlsruhe Institute of Technology

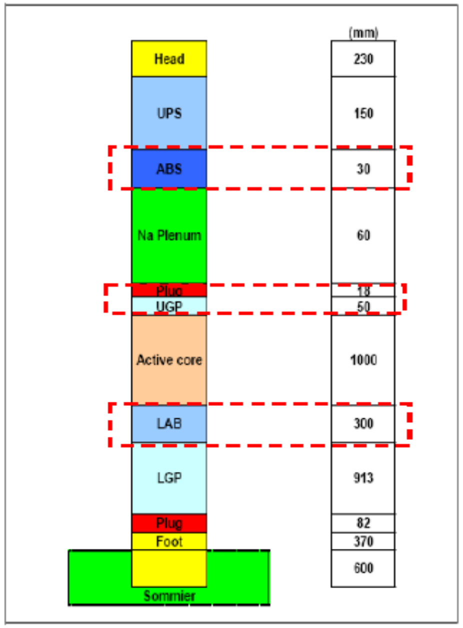


CP-ESFR Oxide Core

Prevention of Core Disruptive Accidents :

Optimization studies to reduce the void worth in the ESFR core

- Larger Na plenum
- Na shifted closer to the core by removing UAB and shorten gas plenum
- Adoption of lower fertil blanket instead of steel reflector
- Absorber layer (B_4C natural Boron) above the Na plenum.



CP-ESFR Oxide Core :
Axial Layout

	REF	CONF2	
	ERANOS-2.2	MCNP	ERANOS-2.2
	keff	keff (std)	keff
Full Na	1.00930	1.01264 (0.00061)	1.01141
Core void	1.02515	1.02683 (0.00055)	1.02618
Extended void	1.02179	1.01699 (0.00063)	1.01651
Na plenum void	-	1.00661 (0.00060)	1.00404
	Void effects (pcm)		
SVRE	+1532	+1365	+1423
Extended SVRE	+1211	+422	+496
Only Na plenum void	-	-592	-726

The core void (SVRE) is slightly reduced.

The extended void (extended SVRE) is reduced by ca. 2 $ with respect to REF

CP-ESFR (7th FP of EU) : Accident Mitigation via Introduction of Controlled Material Relocation (CMR) Measures

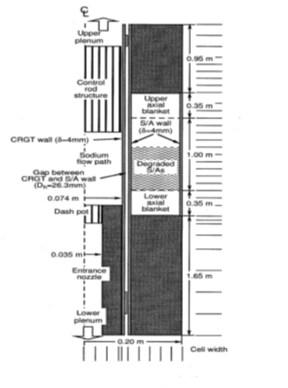
Mitigation of Core Disruptive Accidents :

Optimization studies to allow a Controlled Material Relocation (CONF3B & CONF3C Cores)

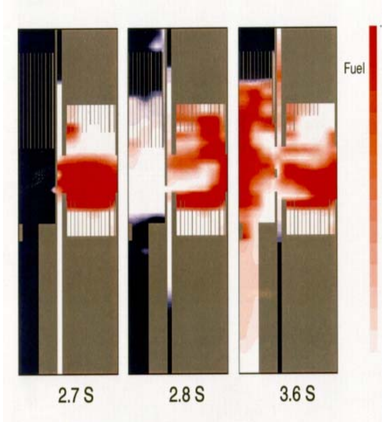
- Fuel discharge via CRGT
- Fuel discharge via empty pins in subassembly
- Fuel discharge via empty subassemblies (CONF3B & 3C)

	CONF2		CONF3B		CONF3C	
	MCNP	ERANOS2.2	MCNP	ERANOS2.2	MCNP	ERANOS2.2
	Keff					
Full Na	1.01264	1.01141	1.00983	1.00891	1.00922	1.00802
	MCNP	ERANOS2.2	MCNP	ERANOS2.2	MCNP	ERANOS2.2
	Void effects (pcm)					
SVRE	1365 ± 60	1423	1325 ± 60	1317	1206 ± 60	1320
Extended SVRE	422 ± 60	496		349	347 ± 60	336
Extended SVRE + „empty“ SA			125 ± 60	-209	327 ± 60	164

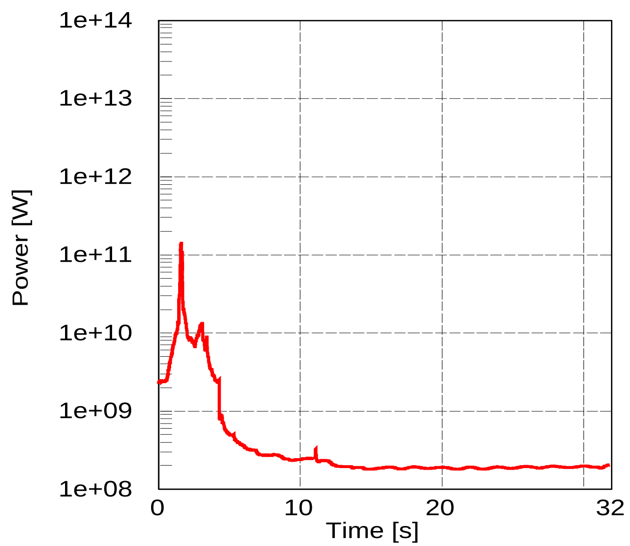
- The extended void effect is further reduced
- Voiding of “special” SAs (for fuel ingress) reduce reactivity
- Adoption of “special” SAs provides additional paths for fuel relocation



. Geometric model for analysis of fuel removal through CRGT channel.



Fuel relocation via CRGT



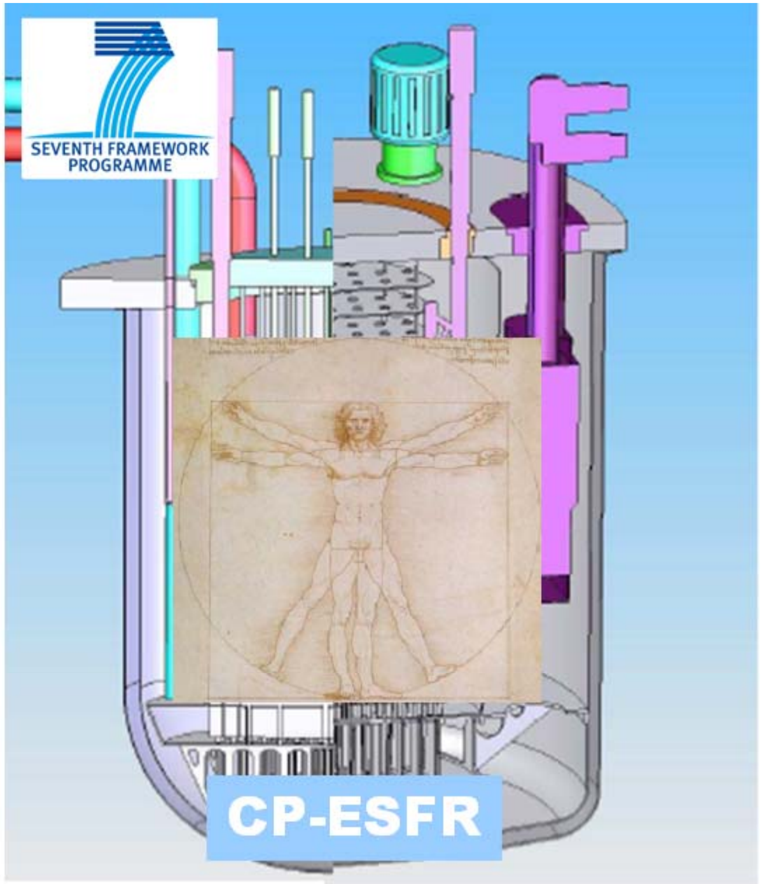
SIMMER Simulation of Core Melt Phase with Controlled Material Removal Measures

Safety activities in CP ESFR

Collaborative Project for a European Sodium Fast Reactor

http://www.cp-esfr.eu

with thanks to A. Vasile (CEA)



- Objectives
- Description of the Project
- Safety activities
- Conclusions

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 Plutonium usage and 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

Consistency & Assessment — Management

Schedule:

Jan. 2009 - Dec. 2012

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

Safety *(& PRPP)* Work packages

- Safety objectives and design principles :
  - Technology neutral Safety objectives and Principles
  - Design strategy with respect to safety
- Implementation of a whole set of “defence-in-depth” levels with the corresponding provisions, and identification of incidents/accidents which are representative for DB and DEC
- Studies of representative transients and accident scenarios for design basis and beyond design basis events
- Comparative evaluations of provisions to decrease the risk related to core degradation accidents and the associated potential of mechanical energy releases
- Containment measures and core catcher designs for demonstration of long term cooling ability
- Evaluation of modelling capabilities of accident scenarios

Safety & *PRPP*

Safety objectives and design principles

- **Technology neutral Safety objectives and Principles :**

  · Safety objectives and principles.
  · Rules for safety analysis and events considered in the safety demonstration.
  · Consideration of hazards.
  · Safety classification and qualification of components.
  · Probabilistic Safety Assessment.

- **Characteristics of a robust safety architecture**
- **Main safety issues based on operating and licensing feedback**
  - **Prevention of general core meltdown accident**
    - Quantitative probabilistic targets
    - Provisions for the prevention
    - Lines of improvement
    - Proposed R&D to prevent the core meltdown accidents
  - **Mitigation of consequences of core meltdown accident**
    - Local fuel meltdown
    - Whole core meltdown
    - Phenomena releasing mechanical energy
  - **"Practically eliminated" situations**
  - **Other specific risks linked to Sodium**
  - **Hazards**

Safety & *PRPP*

cea

energie atomique • energies alternatives

- **Evaluation of modelling capabilities of accident scenarios**

1. Core evolution and in-vessel structures behaviour in transients of the design basis domain and the core degradation phenomenology
2. Release and transfer of dangerous products
3. Pool, mixed and spray sodium fires
4. Sodium-water, sodium-water-air and sodium – concrete reactions

The respective PIRT process systematically consist in

- the identification of the phenomenology,
- the evaluation of the importance of the phenomena on the evolution and consequences of the accident,
- the review of available results of the respective R&D work (main outcomes, pending questions) and
- the evaluation of the models implemented in the different available tools (adequate modeling, validation, evolution capability,..)

Education & Training safety related activities

Workshops

- Na and other coolants: in-reactor behaviour and safety, CEA Cadarache, Nov. 2009

- Functional analysis and design safety
  CEA Cadarache, Nov. 2010
- ESFR Engineering Aspects.
  Univ. Rome, Nov. 2011
- ESFR Reactor Physics and Safety.
  Univ. Madrid, 8 – 11 October 2012

Doctoral dissertations

- 1 Experimental PhD, CEA (Finished)
- 3 Modelling PhDs, CEA, NRG, Univ. Madrid

Conclusions

- The European 7th FP CP ESFR Project is contributing to:
  - Investigate a variety of innovative options for the plant and core design to improve the safety features of future SFRs
  - Rebuilt and develop the European expertise on SFR
- 25 European partners (Research laboratories, utilities, designers, vendors and TSO) are involved.
- Results of the Project activities are partly made available to partners of the GIF initiative