Modelling of circulating fuel reactors based on the Molten Salt Reactor Experiment

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Tomasz Hanusek

Division of Nuclear Energy and Environmental Studies

tomasz.hanusek@ncbj.gov.pl

Fundusze Europejskie Wiedza Edukacja Rozwój

Rzeczpospolita Polska

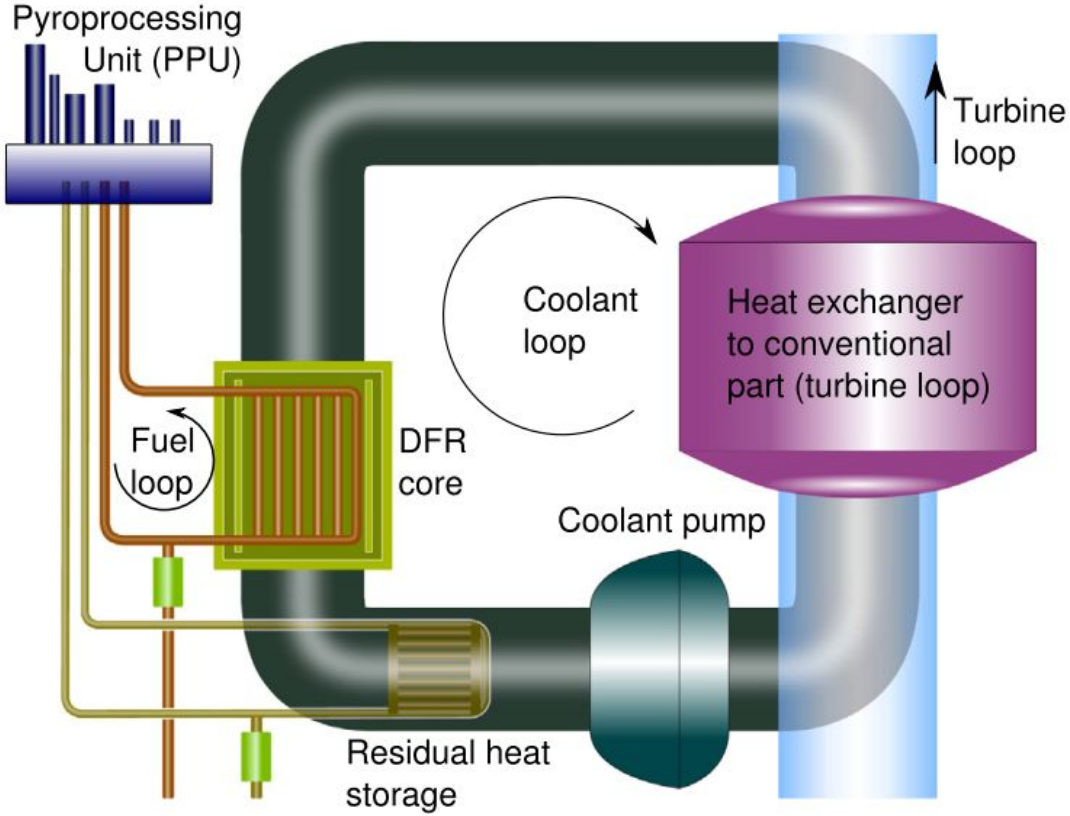
Unia Europejska Europejski Fundusz Społeczny

New reactor concepts and safety analyses for the Polish Nuclear Energy Program
POWR.03.02.00-00.I005/17

Outline of presentation

- Aim of my PhD
- MSRE reactor
- Tools and model of MSRE
- Results
- Remarks

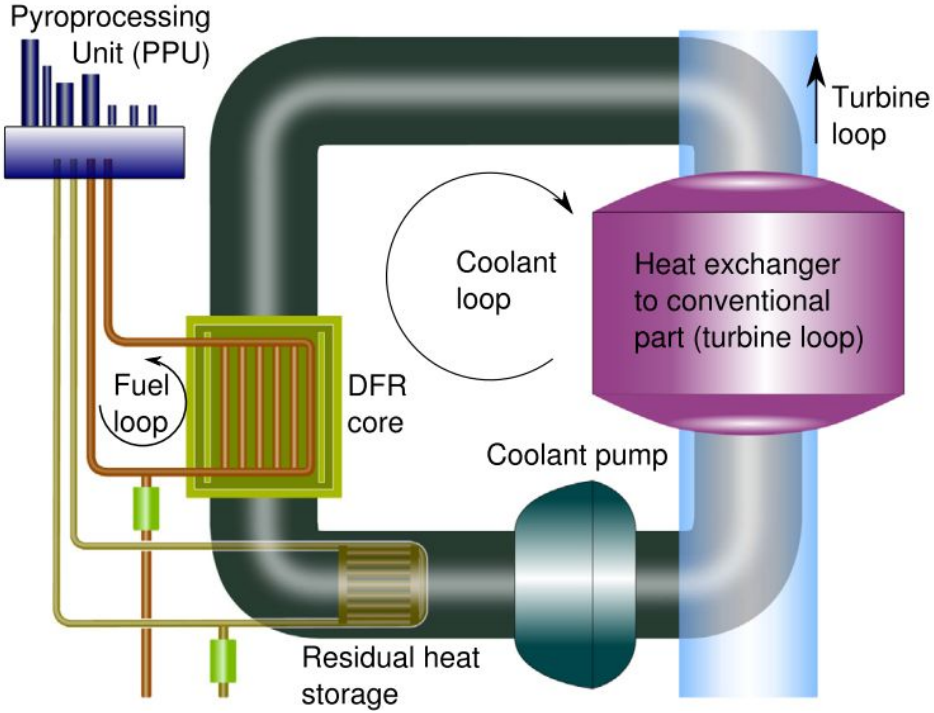
Concept of Dual Fluid Reactor

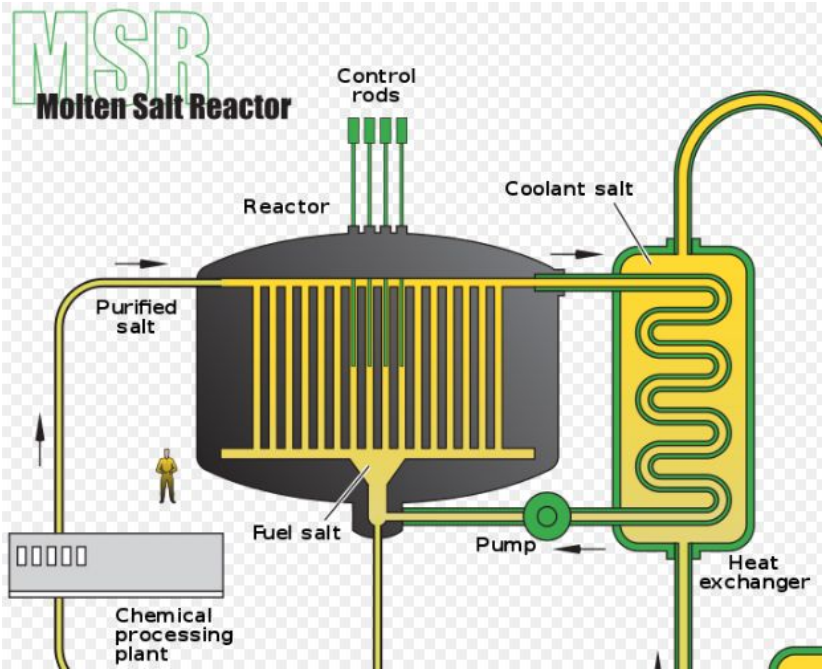


[3] http://dx.doi.org/10.1016/j.anucene.2015.02.016

There is no dual fluid reactors. How to check if results of simulations will describe the reality?

Answer: Validation

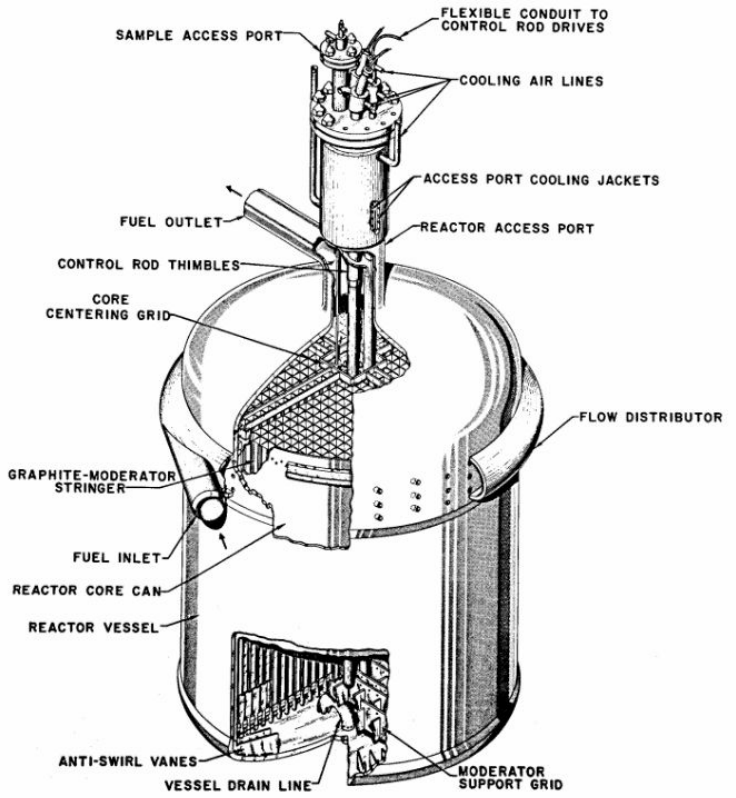


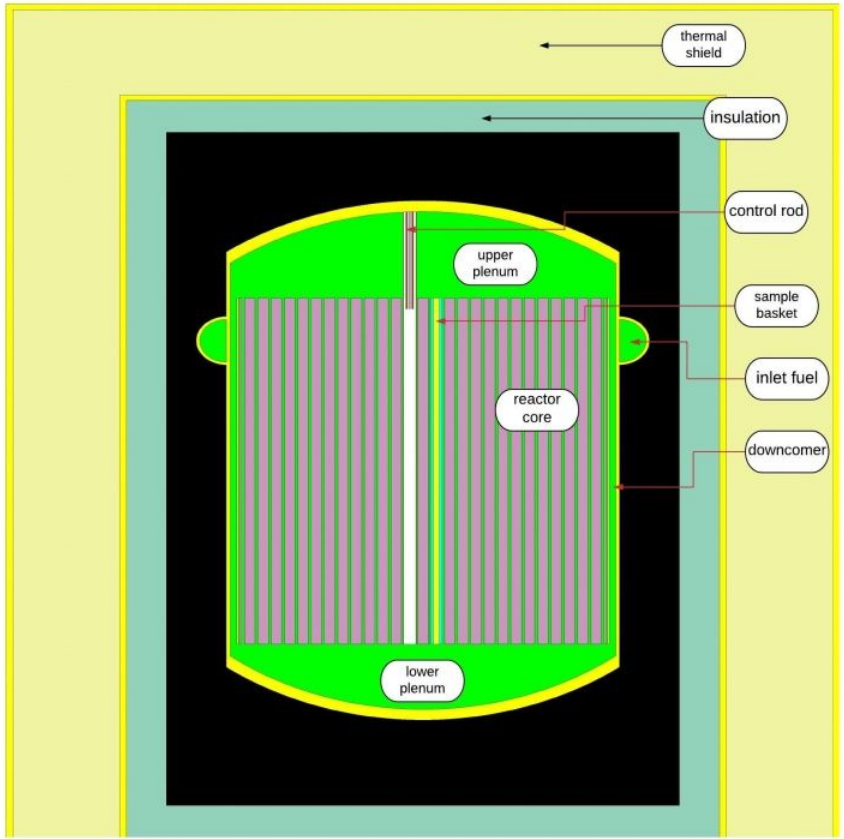


[3] http://dx.doi.org/10.1016/j.anucene.2015.02.016

[7]https://www.gen-4.org/gif/jcms/c_42150/molten-salt-reactor-msr

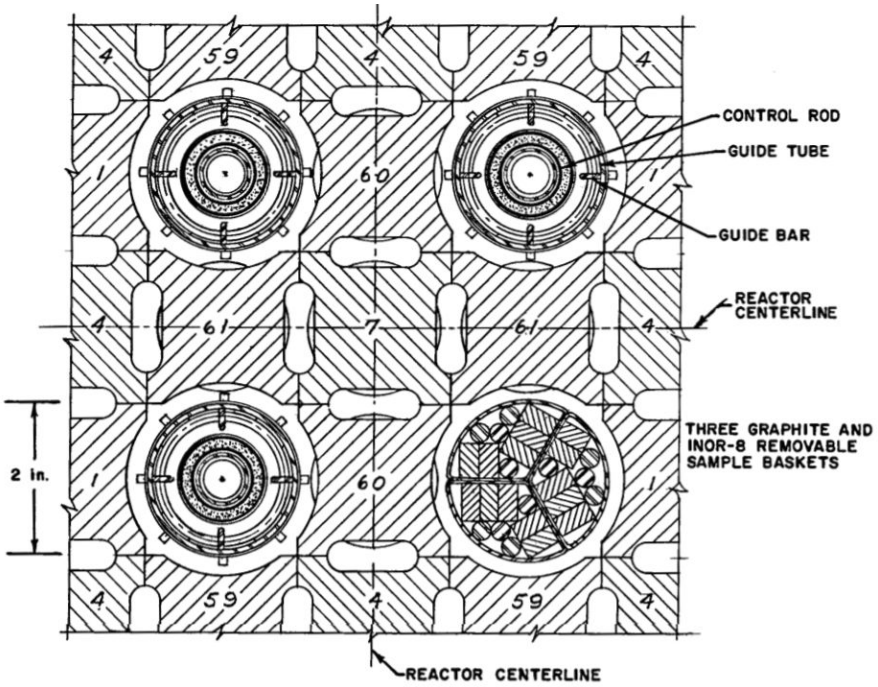
MSRE model in Monte Carlo - Serpent 2

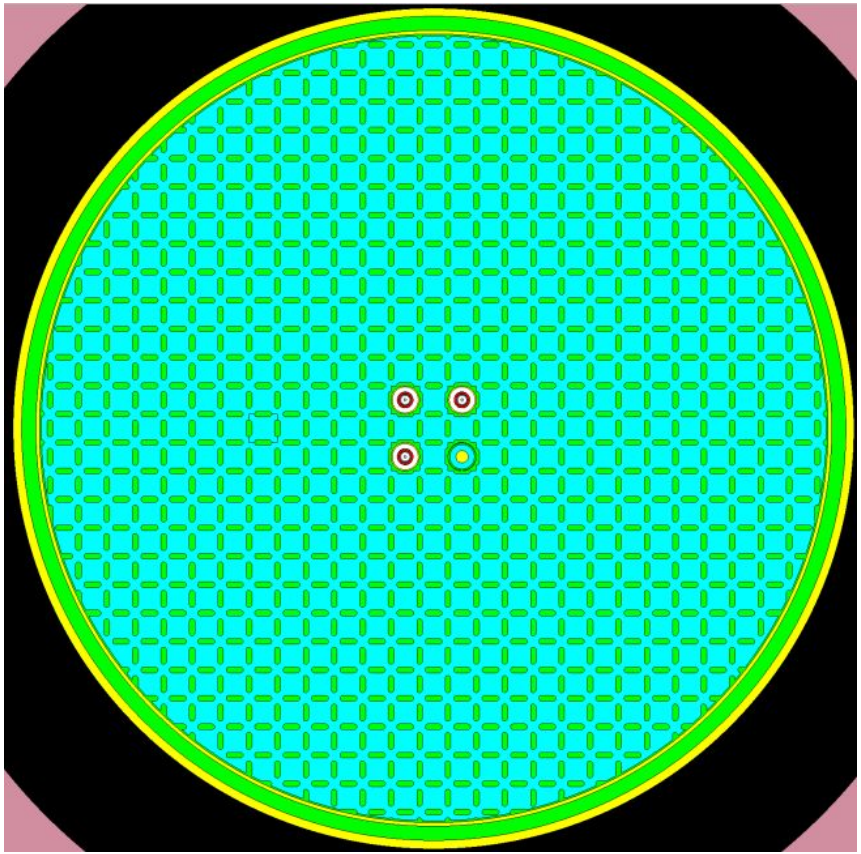




[10] MSRE design and operations report, part I. Description of reactor design. Oak Ridge National Laboratory

MSRE model in Monte Carlo - Serpent 2





[10] MSRE design and operations report, part I. Description of reactor design. Oak Ridge National Laboratory

Model of MSRE criticality experiment

Case	K effective
Fratoni MSRE workshop [11] (SERPENT 2, ENDF/B-VII.1 cross sections)	1.01276 ± 0.000098
Authors results (SERPENT 2.1.31, ENDF/B-VII.1 cross sections)	1.00952 ± 0.00013

Power distribution using neutron-photon calculations

decay heat %	fission energy deposition %	gamma energy deposition %	tot. energy deposition %	
2.336	70.827	2.055	75.218	fuel core
-	-	3.9	3.9	graphite
1.052	7.001	0.443	8.495	upper head
0.985	5.323	0.321	6.630	lower head
0.213	2.840	0.466	3.518	Downcomer
0.277	0.336	0.036	0.649	fuel inlet
1.571	0.000	0.000	1.571	rest of primary loop
6.47	**86.328**	**7.220**	**100**	sum

Modify standard Point Kinetic Model (PKM)

Point kinetic model for solid fuel:

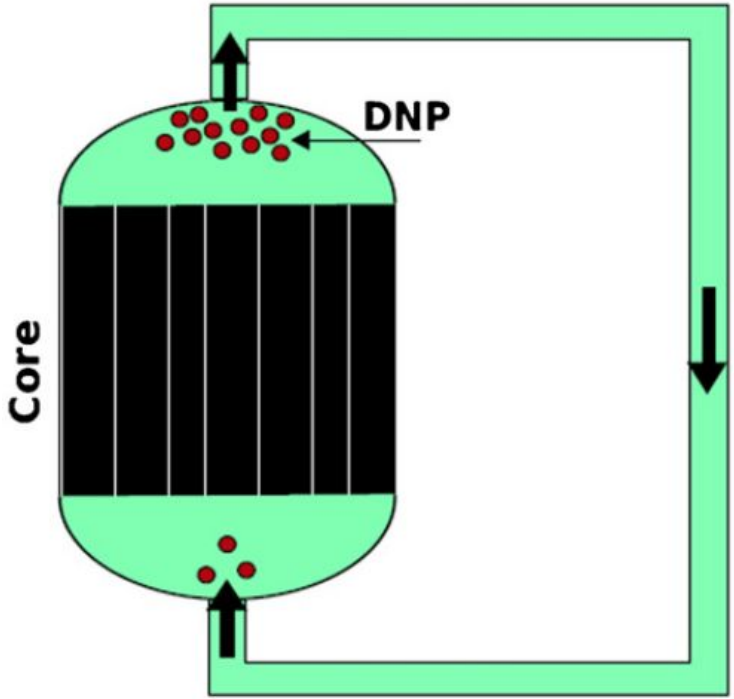
$$\frac{dn(t)}{dt} = \frac{\rho(t)-\beta}{\Lambda} n(t) + \sum_{i=1}^{I} \lambda_i C_i$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} n(t) - \lambda_i C_i$$

Point kinetic model for circulating fuel:

$$\frac{dn(t)}{dt} = \frac{\rho(t)-\beta}{\Lambda} n(t) + \sum_{i=1}^{6} \lambda_i C_i$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} n(t) - \lambda_i C_i - \frac{C_i(t)}{\tau_c} + \frac{C_i(t-\tau_e)}{\tau_c} * e^{-\lambda_i \tau_e}$$



[12] doi:10.1016/j.nucengdes.2011.08.002

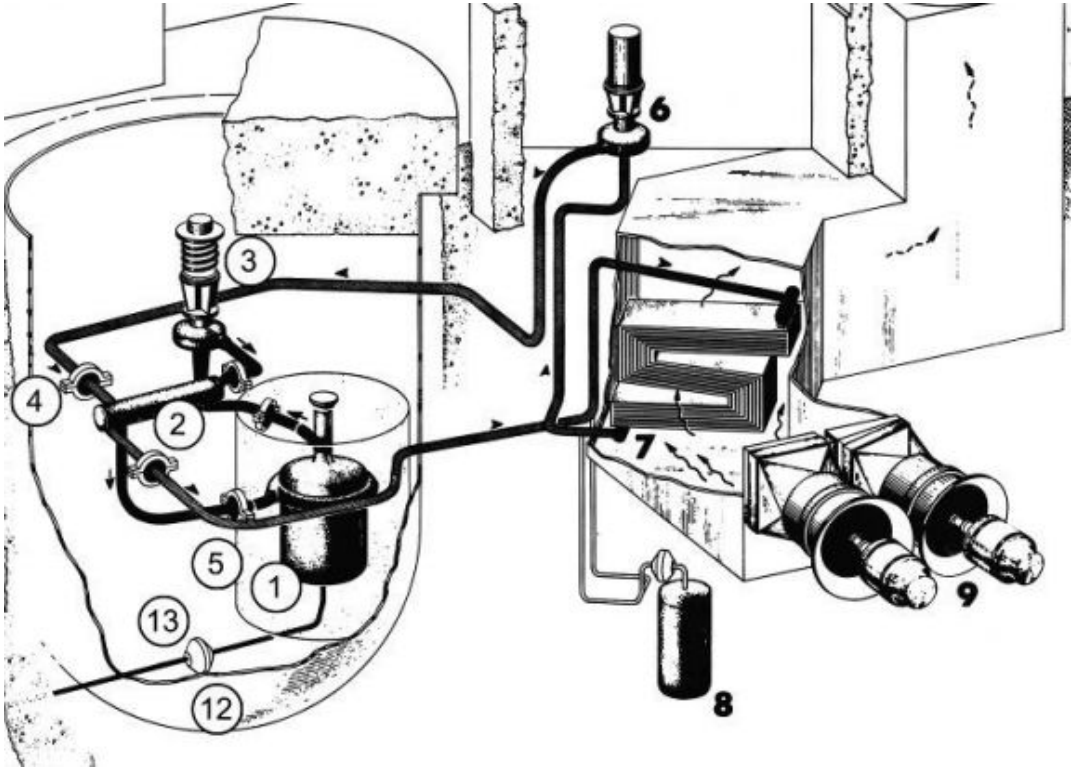
Tool for coupled calculation – TRACE (1/2)

- The TRAC/RELAP Advanced Computational Engine (TRACE - formerly called TRAC-M) is the latest in a series of advanced, best-estimate reactor systems codes developed by the U.S. Nuclear Regulatory Commission for analyzing transient and steady-state neutronic-thermal-hydraulic behavior in light water reactors
- It can also model phenomena occurring in experimental facilities designed to simulate transients in reactor systems [4]
- It is using finite volume numerical methods for flow equation
- Eable to model 1D or 3D flow
- 3 balance equation: energy, mass and momentum
- Eable to model 2-phase flow

Tool for coupled calculation – TRACE (2/2)

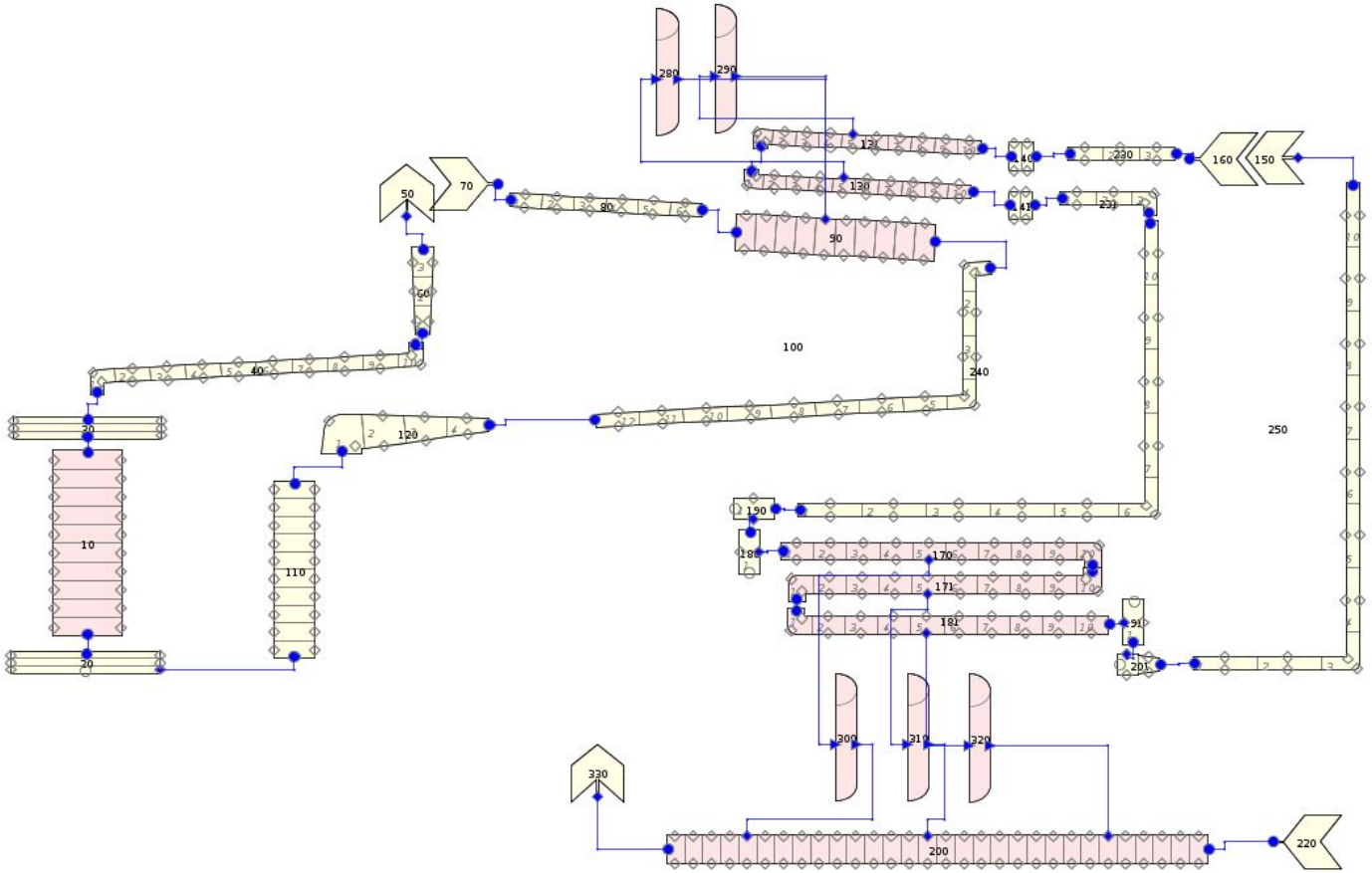
- TRACE – NRC code validated code for accidents in PWR, dedicated also for BWR.
- Things developed to model MSRE:
  - make point kinetic neutronic solver with modified equations
  - Add new fluids and structure materials, because TRACE has just few built-in fluids (water, heavy water, nitrogen, lead-bismuth, sodium, air)

MSRE

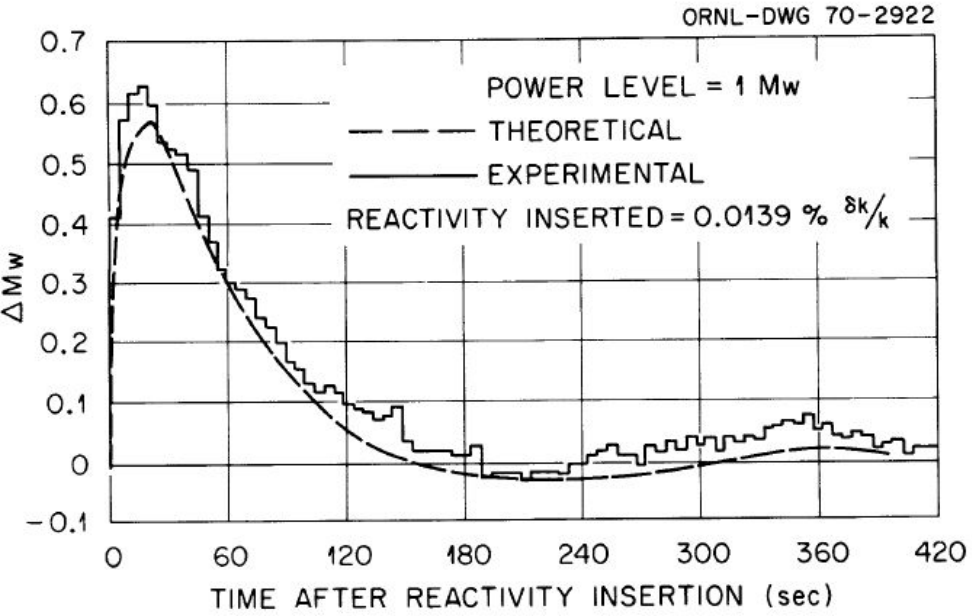


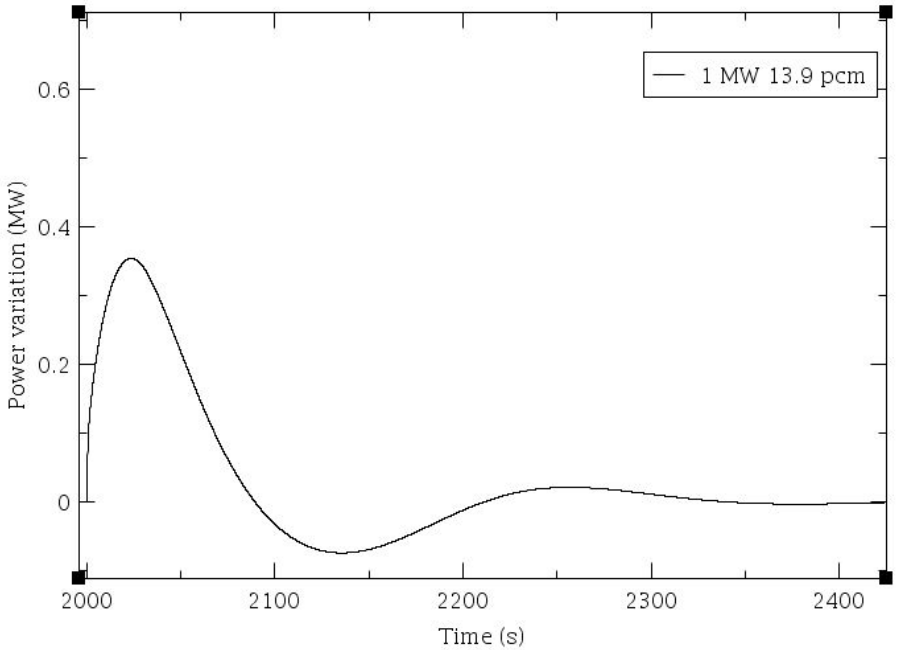
An Account of Oak Ridge National Laboratory's Thirteen Nuclear Reactors. ORNL, 2010 [5]

Model of MSRE in TRACE



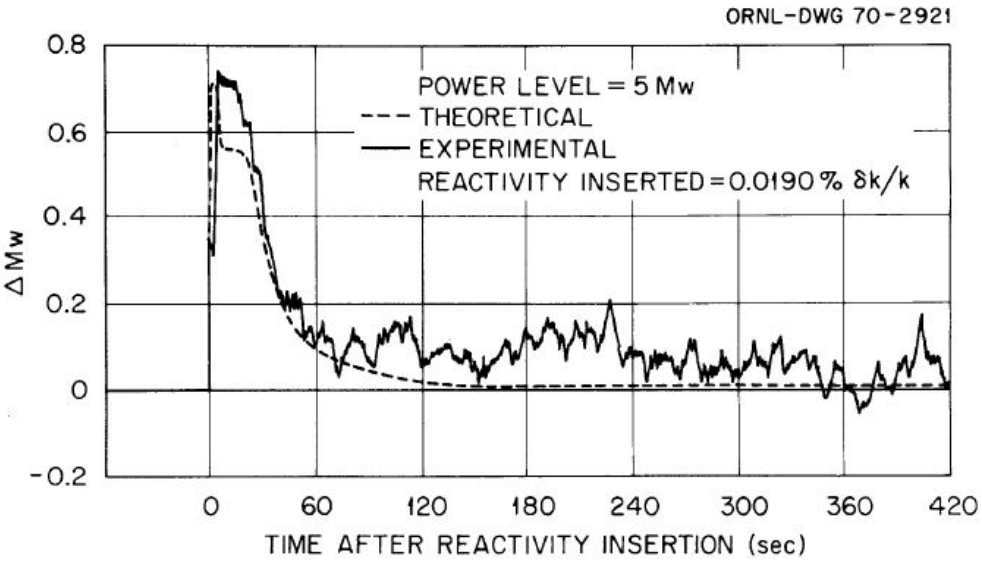
1 MW and 13.9 pcm reactivity inserted results

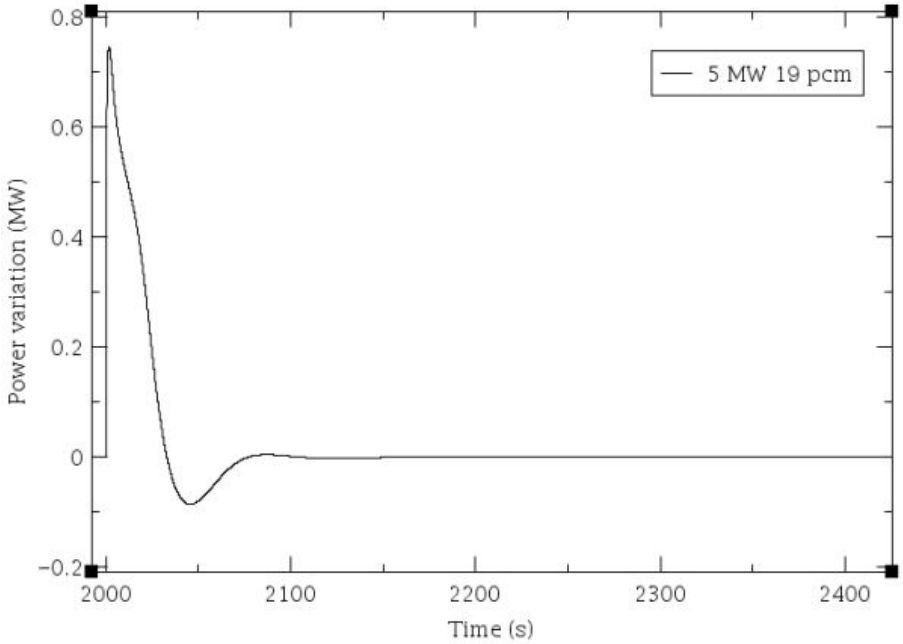




Experimental dynamic analysis of the MSRE with 233-U fuel [13]

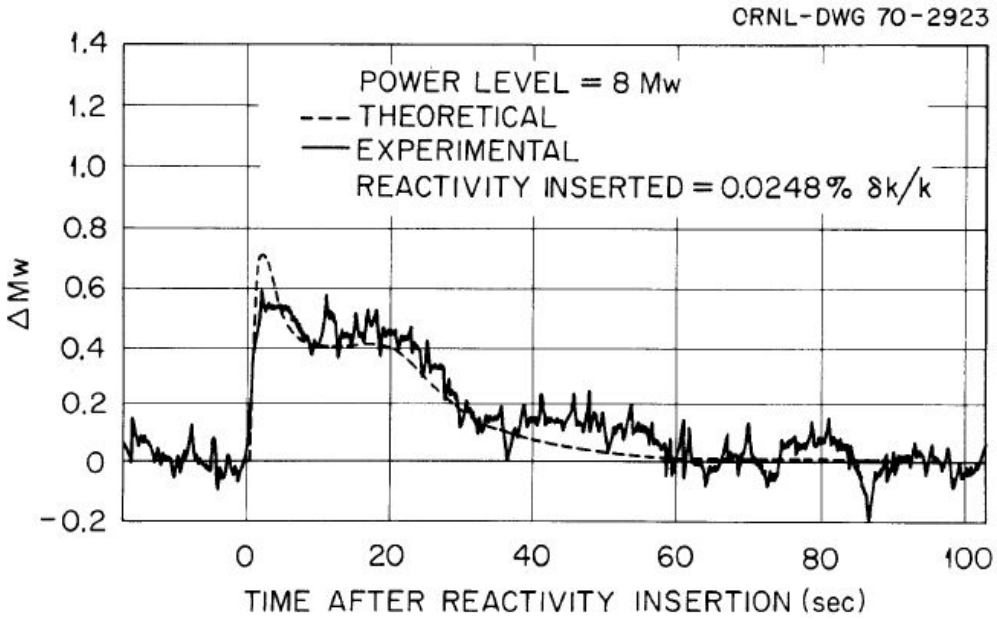
5 MW and 19 pcm reactivity inserted results

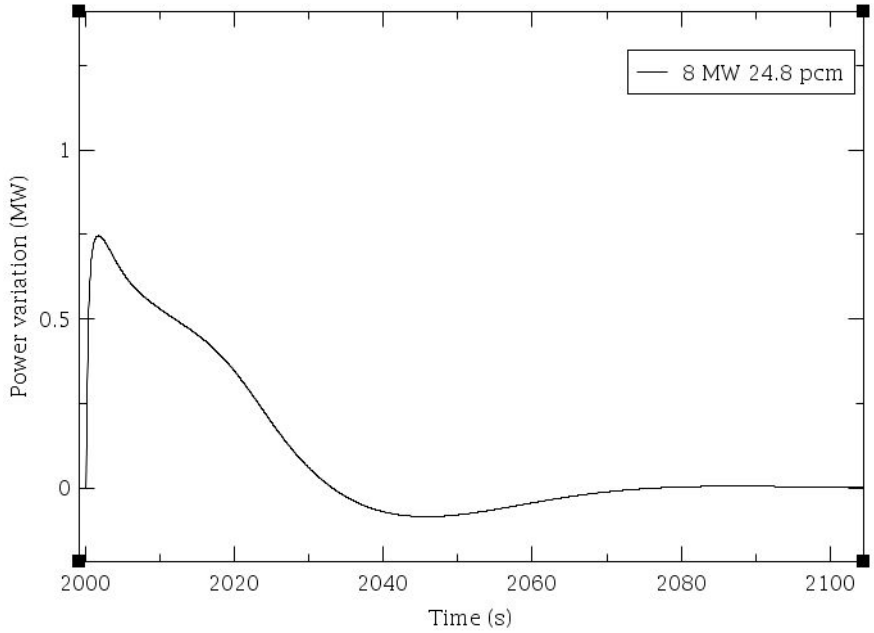




Experimental dynamic analysis of the MSRE with 233-U fuel [13]

8 MW and 24.8 pcm reactivity inserted results





Experimental dynamic analysis of the MSRE with 233-U fuel [13]

Remarks

1. Still developing results of MSRE in order to publish it as reference paper

2. Informations and hints:
   - there is new version of Serpent 2 on cluster: 2.1.31
   - use neutron-photon calculation to get better results in term of power distribution
   - neutron-photon mode can be also very useful for shielding calculations

Literature

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3. Huke A., et al.: *The Dual Fluid Reactor – A novel concept for a fast nuclear reactor of high efficiency*. Annals of Nuclear Energy, 2015
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Literature

9. Leppänen J., et al.: The Serpent Monte Carlo code: *Status, development and applications in 2013*. Annals of Nuclear Energy, 2015
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13. Steffy R., et al.: *Experimental dynamic analysis of the MSRE with 233-U fuel, ORNL 1970*

Thank you for attention

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