Transient calculations for the DFRm

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New reactor concepts and safety analyses for the Polish Nuclear Energy Program
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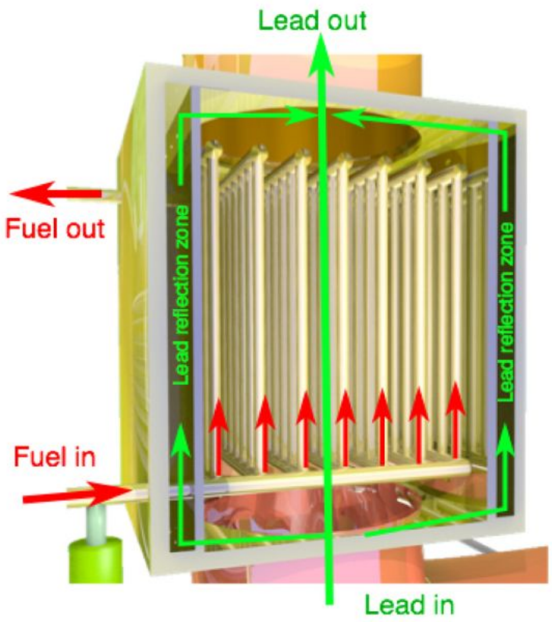
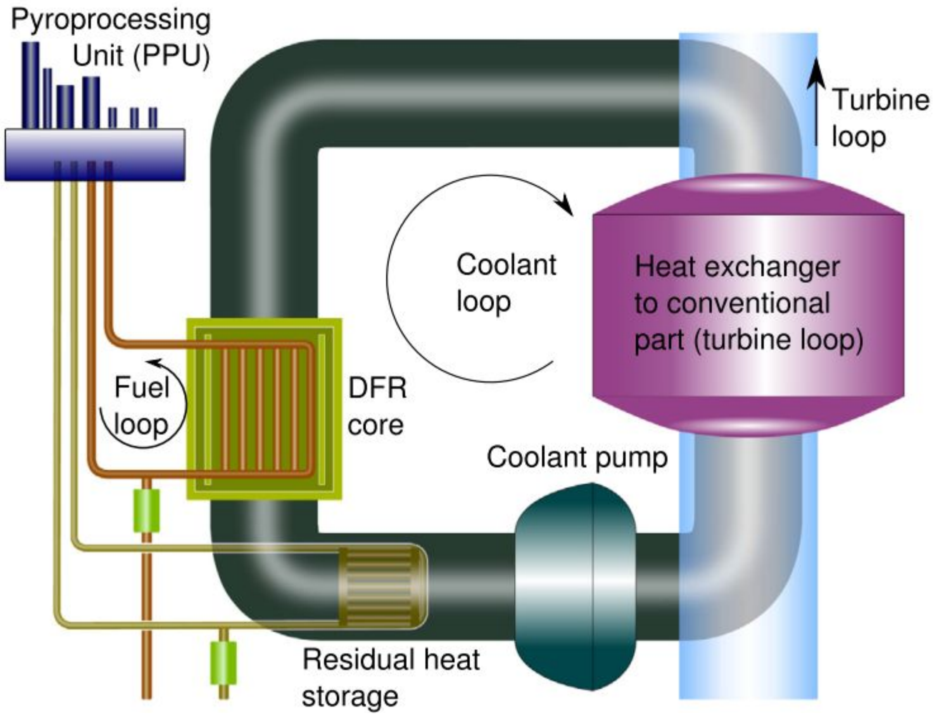
New concept of nuclear reactor DFR (1/2)

DFR is reactor which combine features of molten salt reactor (MSR) and lead-cooled fast reactor (LFR).
Coolant: pure lead
Fuel DFRs: UCl_3 and $PuCl_3$ [1]
Fuel DFRm: ^{54}Cr – 4.78%, ^{235}U – 12.8%, ^{238}U – 82.42% [2]
Material for fuel pipes: SiC
Average fuel temperature: $1150^{0}C$

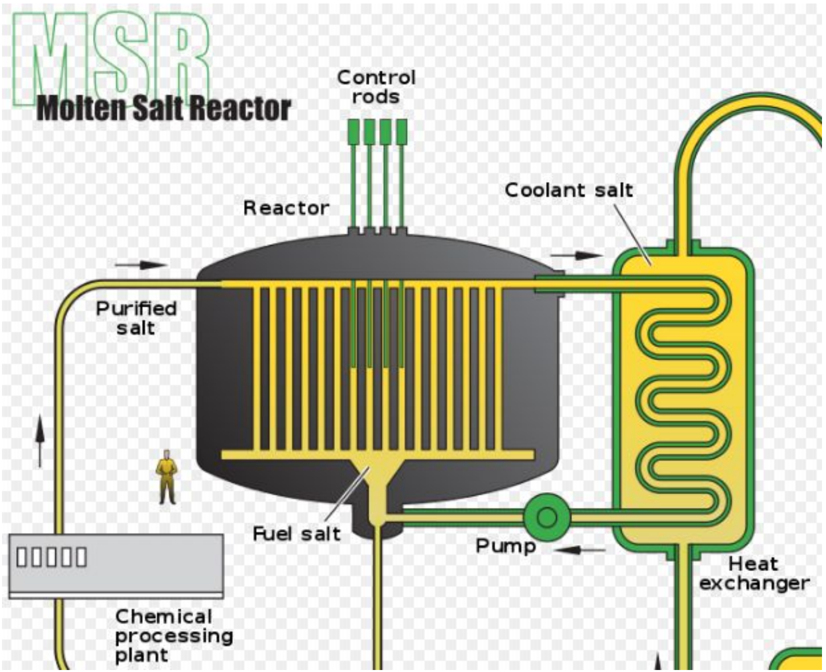


[3]Core picture: http://dx.doi.org/10.1016/j.anucene.2015.02.016

Concept of DFR (2/2) vs MSR



[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

Why we should look at this DFR?

No.	Features	DFRm	MSR	LFR	HTGR	LWR
1	Doubling time (y)	<8	15-20	10	30	not applicable
2	Waste storage time (y) PUREX	300	300	10k	10k	10-100k
3	Waste storage time (y) electro refinement	300	300	300	300	10-100k
4	Isotope production	Yes, very good	Yes, good	Limited	Uneconomical	Uneconomical
5	Burnup	99%	99%	15-20%	20%	few %
6	Cooling after LOOP	Inherent	Inherent	Active	Inherent	Active
8	Pressure in nuclear part	few bars	few bars	few bars	few MPa	15 MPa
9	Electric efficiency	Up to 60%	Up to 50%	Up to 50%	Up to 60%	Up to 36%

[8] Huke A., et al.: Dual Fluid Reactor. Annals of Nuclear Energy, 2015

What we still do not know about DFRm?

- Type o pump in primary and secondary loop
- Exact geometry of inlet/outlet region of the core
- Transient behaviour of the reactor
- Corrosion processes in the core
- Effects of neutron irradiation
- Startup shutdown procedure

What is the aim of my PhD?

- **The goal is to check behaviour of Dual Fluid Reactor (DFR) in transients situations.**

- Examples of transients:
  - loss of heat sink
  - loss of primary pump
  - loss of primary and secondary pump
  - Reactivity insertion
  - Unprotected overcooling
  - Unprotected overheating

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)

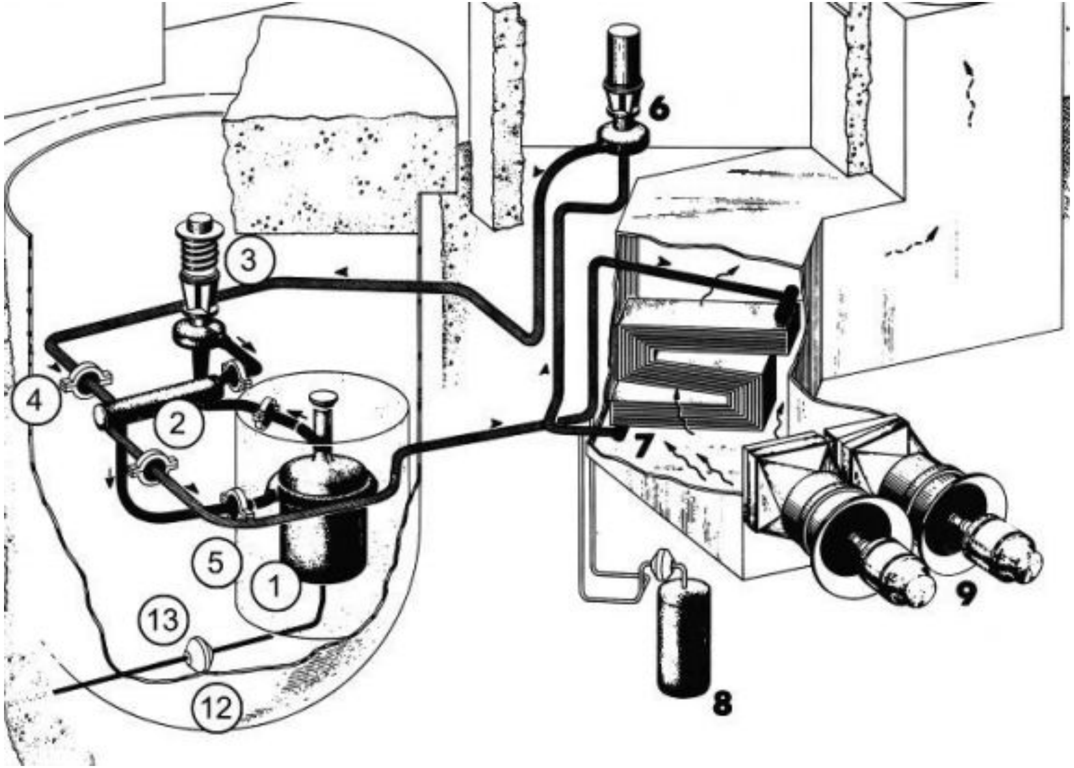
- TRACE – NRC code validated code for accidents in PWR, dedicated also for BWR.
- Things to develop to model DFR:
  - Change neutronic equation
  - Add new fluids and structure materials

There is no DFR reactors, how to check if results of simulations will describe the reality?

Answer: Benchmark!

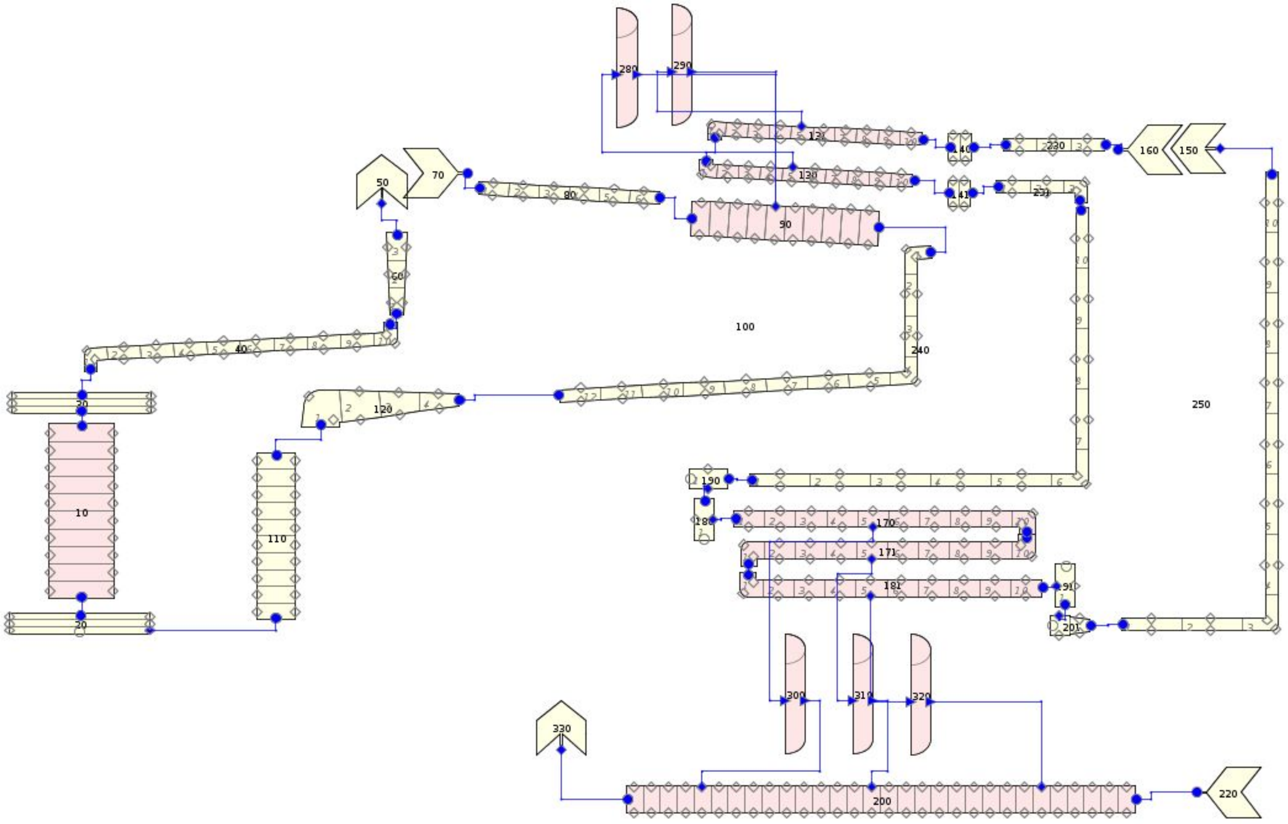
- Model MSRE (Molten Salt Reactor Experiment) to make benchmark with experimental data
- Then, Model DFR

MSRE



MSRE design [5]

Model of MSRE in TRACE



Modify standard Point Kinetic Model (PKM)

Point kinetic model for solid fuel:

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

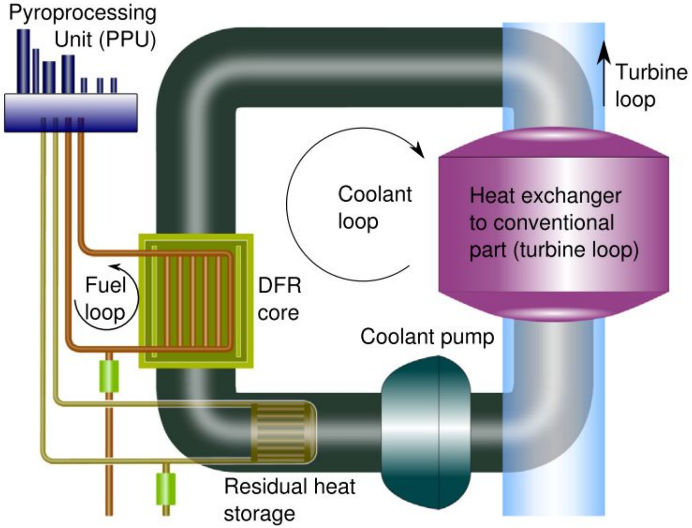
$$\frac{dC(t)}{dt} = \frac{\beta_i}{\Lambda} n(t) - \lambda_i C_i$$

Point kinetic model for circulating fuel:

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

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

[6]



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

Point kinetic model for MSRE in TRACE

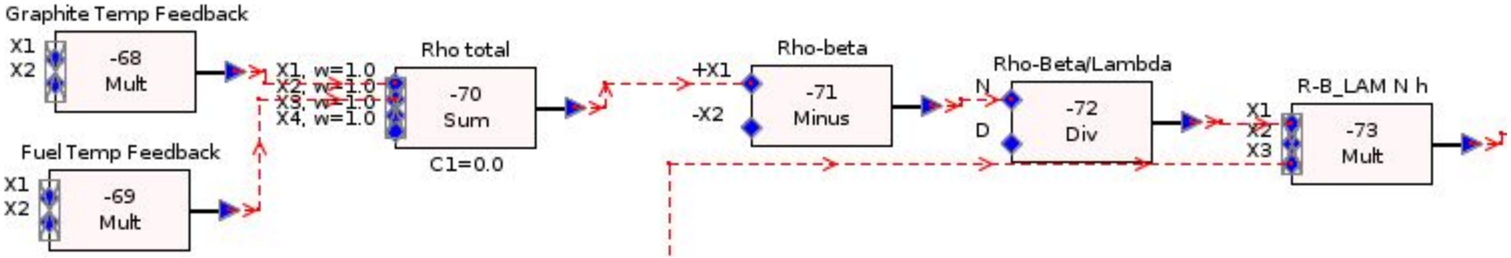
Circulating fuel point kinetic equation:

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

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

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

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



Tool for coupled calculation – TRACE (3/3)

- Drawbacks of TRACE:
  - TRACE has embedded only 7 fluids (water, heavy water, air, lead-bismuth, helium, sodium, nitrogen)
  - User can add new fluid, but only 1 per simulation and only from NIST database (REFPROP) - there is lack of liquid metals
  - Neutronic in TRACE is just PKM, I hope in future PARCS code which is 3D diffusion code, naturally coupled with TRACE will be used)

Things to faced for now

- Waiting for open-source of TRACE -> Then, it will be possible to modify sodium and lead-bismuth fluids to my purpose

- Another idea:

  Coupled Monte Carlo (probably it will be Serpent) with CFD code, which will be Fluent or OpenFOAM

Literature

1. Wang X.: *Analysis and Evaluation of the Dual Fluid Reactor Concept*, 2017
2. Sierchuła J., et al.: *Determination of the metallic fuel Dual Fluid Reactor (DFRm) design*, 2018
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
4. Bajorek S., et al.: *TRACE V5.0 USER'S MANUAL*. NRC, Washington, 2012
5. Rosenthal W., et al.: *An Account of Oak Ridge National Laboratory's Thirteen Nuclear Reactors. ORNL, 2010*
6. Cammi A., et al.: *Dimensional effects in the modelling of MSR dynamics: Moving on from simplified schemes of analysis to a multi-physics modelling approach.* Nuclear Engineering and Design, 2011
7. https://www.gen-4.org/gif/jcms/c_42150/molten-salt-reactor-msr
8. Huke A., et al.: *Dual Fluid Reactor.* Annals of Nuclear Energy, 2015

Thank you for attention

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