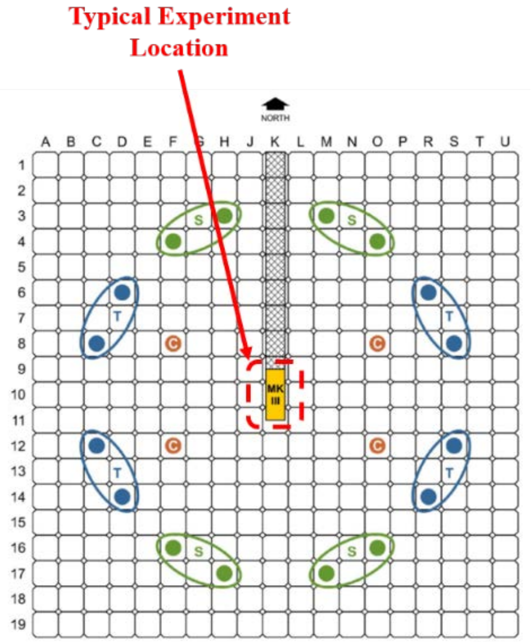
TWERL for TREAT Pre-conceptual design questions

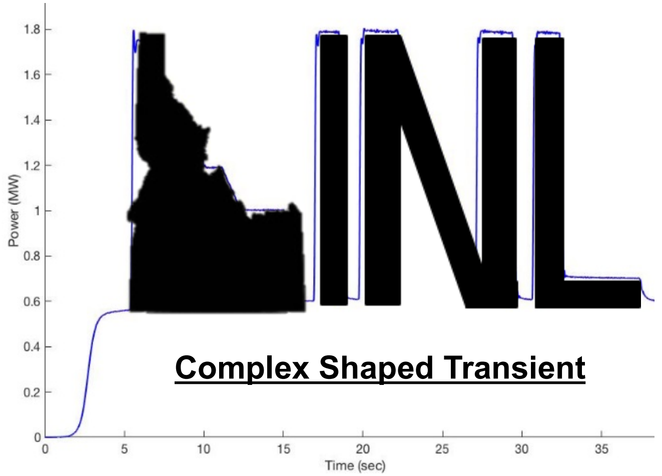
Aaron Epiney

International Relap5 User Group Meeting (IRUG)
Idaho Falls, April 18-19, 2019

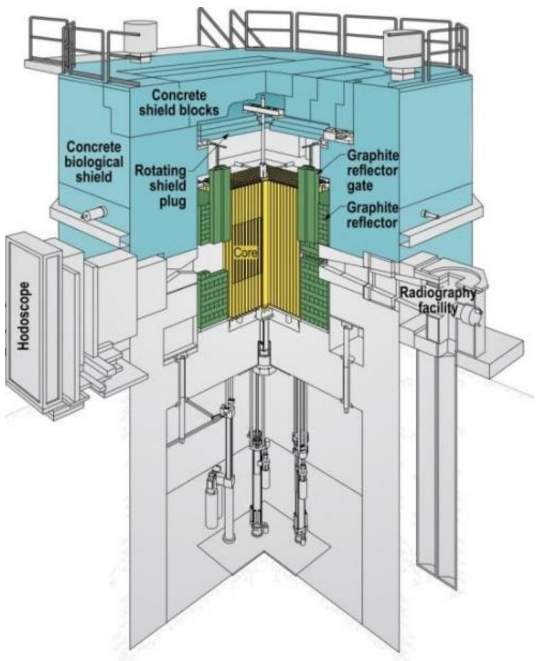
TREAT – Overview

- **Transient Reactor Test (TREAT) has resumed operations in order to support fuel safety testing and other transient science**
- **TREAT: Zircaloy-clad graphite/fuel blocks comprise core, cooled by air blowers**
  - 120 kW steady state, ~20 GW peak in pulse mode
  - Virtually any power history possible within 2500 MJ max core transient energy
  - No reactor pressure vessel/containment, facilitates access for in-core instrumentation
- **Experiment design**
  - Reactor provides neutrons, experiment vehicle does the rest
  - Tests displace a few driver fuel assemblies, handled in cask outside core
  - Recoverable historic designs don't include water-environment vehicles, new designs needed
- **4 slots view core center**
  - 2 in use for fast neutron hodoscope, neutron radiography
- **Collocated at INL with other complimentary facilities**
  - ATR and HFEF
  - Fuel fab and characterization



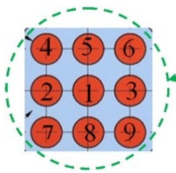


Complex Shaped Transient

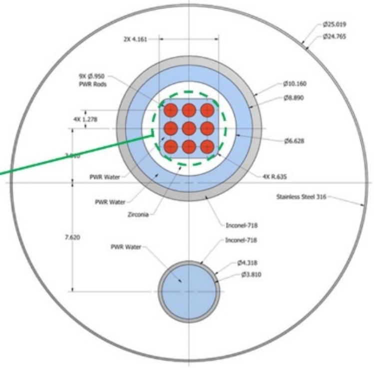


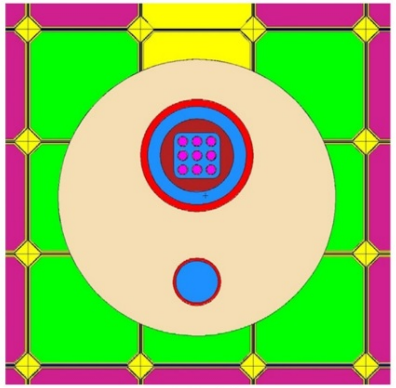
TWERL – Overview

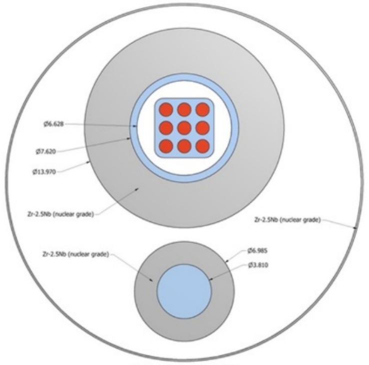
- TREAT Water-Environment Recirculating Loop (TWERL), pump-forced convection ultimately needed to simulate:
  - LWR steady **temperature distribution** prior to accident trigger
  - Flow/temperature distribution in small bundles (TREAT is neutronically capable of driving high burnup **9-rod bundle** to failure limits)
  - Post failure fluid-assisted behavior (**fuel sweep out**)
  - Timing of thermal hydraulic events (dry-out duration, life **after DNB**)
- Current efforts focused around thermal hydraulic performance comparison
  - **System codes simulation of loop options** and typical LWRs
  - Benchmarking against prototype loop recently built at OSU
- Building heavily upon Super-SERTTA design for 2022-2023 deployment

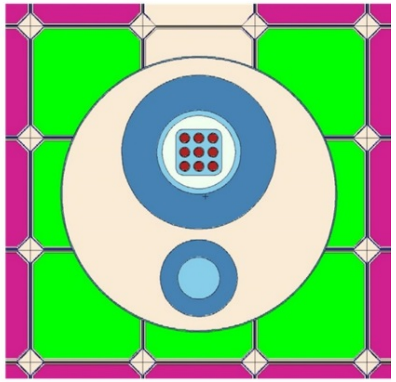


Rod Numbering Scheme


9-Pin Super-TWERL
Inconel version
Dimensions in cm


MCNP Rendering


9-Pin Super-TWERL
Zircaloy Version
Dimensions same as Inconel version except where noted


MCNP Rendering

TWERL – Pre-conceptual design

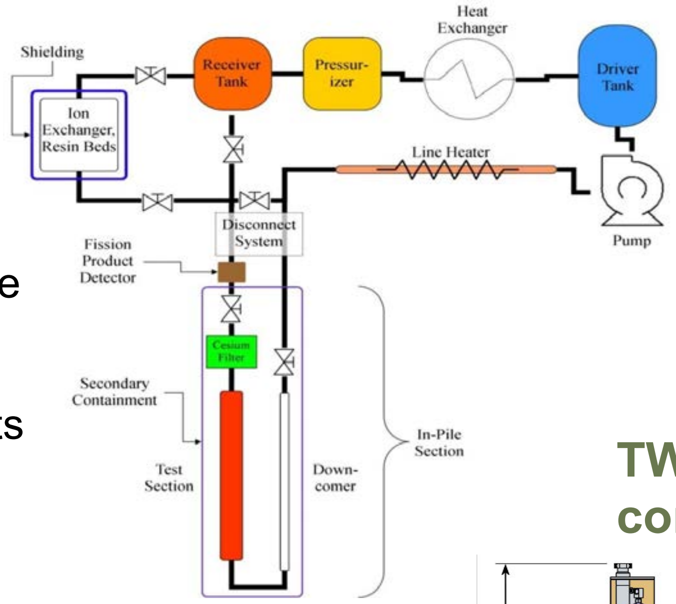
- Currently in its pre-design phase

- **?? Question ??**
  - **"self-contained" loop:** whole assembly including pump, heat exchanger and other components fits in the experiment opening in the TREAT reactor
  - **"loop system concept":** only the test section is inserted in the TREAT core while the other components (HX, pump, pressurizer, etc.) are located outside

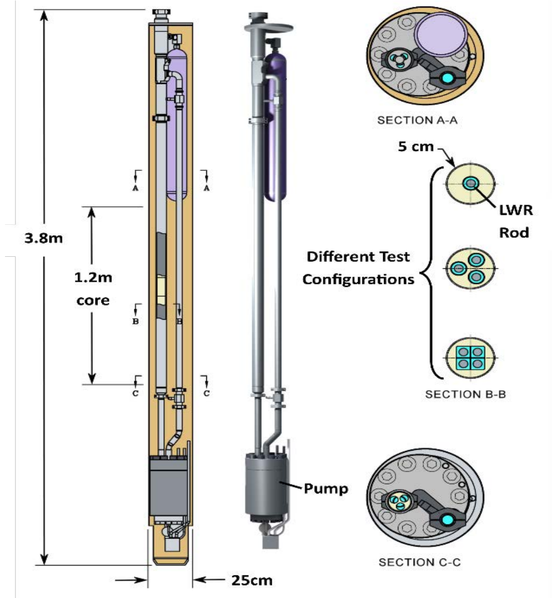
⇒ **Depends on pump** (and heat exchanger (HX)) **size!**

⇒ Need to know **flow losses in the loop** sufficiently to be able to **size the pump** appropriately.

TWERL loop system concept

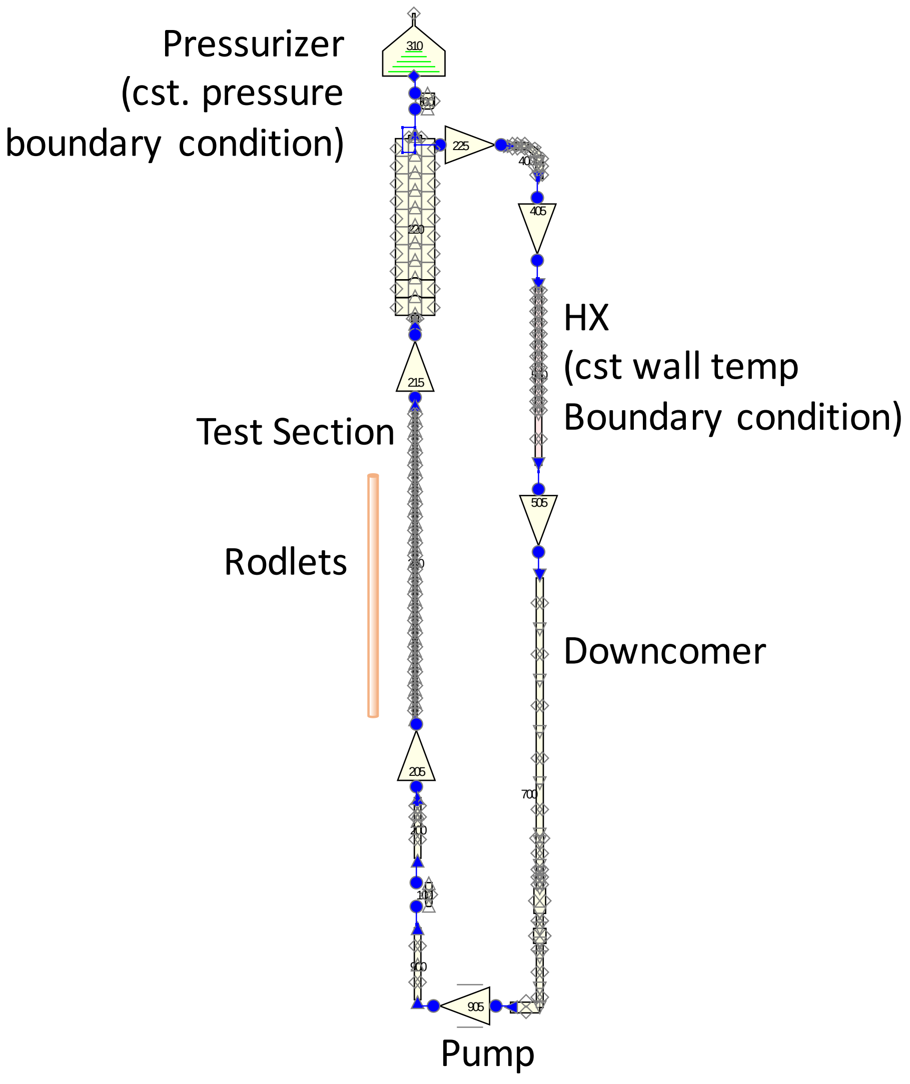


TWERL self-contained concept



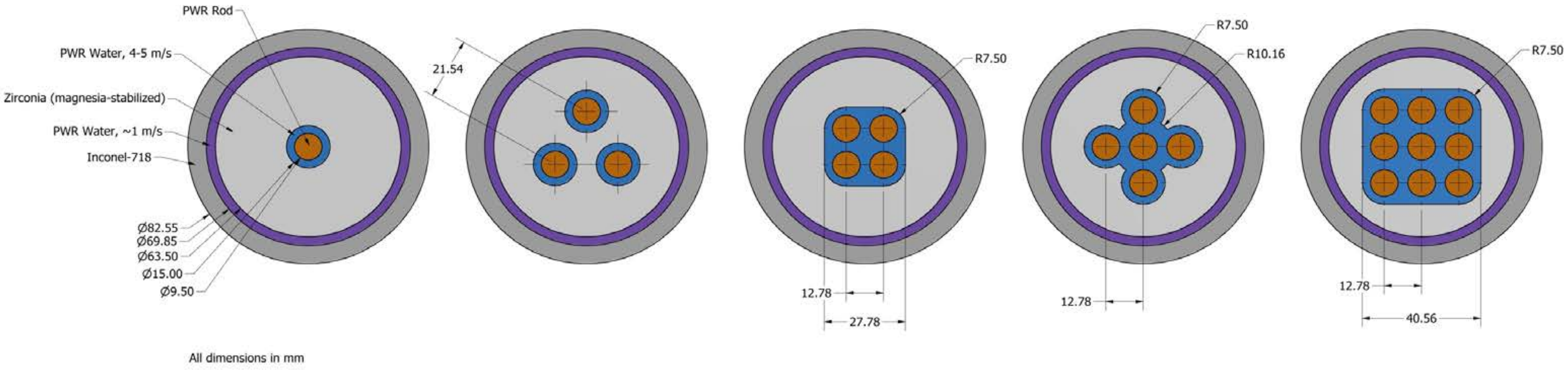
RELAP5 Model

- **RELAP5 hydraulics** only **model** set up
  - **Test Section:** Five different test sections have been modeled and compared.
  - **Heat exchanger:** Three different options for the heat exchanger have been explored.
  - **Pump:** Time Dependent Junction, imposing fluid velocity.
  - **Pressurizer:** Time Dependent Volume, constant pressure of 155 bar is imposed.



Parametric studies

- **Bundle geometries**
  (How does the needed pump size vary with the number of rods in the test section)



# of pins	1	3	4	5	9
Flow area [cm^2]	1.058	3.175	4.399	5.159	9.589
Flow area/pin [cm^2]	1.058	1.058	1.100	1.032	1.065
D_h [cm]	0.550	0.550	0.809	0.698	0.918

Parametric studies

- **Heat exchanger design**
  (How does the needed heat exchanger size vary with the number of rods in the test section and affect the pressure drop)
  - **No heat exchanger**
    - No heat exchanger or a heat exchanger that does not change the flow characteristics in the down-comer.
  - **Simple tube and shell heat exchanger** (for order of magnitude pressure drop estimation)
    - Simplified counter-current, staggered array, tube and shell heat exchangers have been dimensioned for the different test sections.
    - Log Mean Temperature Difference method (LMTD) has been used, invoking the Zukauskas correlation on the shell side and the Dittus-Boelter correlation on the tube side to evaluate the overall heat exchange coefficient.
    - Assuming maximum rodlet length (4ft) and maximum linear power (11kW/ft)

# of pins	1	3	4	5	9
Power to be evacuated [kW]	44	132	176	220	396
Flow rate [kg/s] (core ΔT=40K)	0.159	0.478	0.638	0.797	1.435
HX length [m]	0.343	0.348	0.358	0.373	0.403
HX flow area [m^2]	5.890E-04	1.021E-03	1.139E-03	1.217E-03	1.492E-03
HX D_h [m]	0.005	0.005	0.005	0.005	0.005
HV volume [m^3]	1.644E-03	2.819E-03	3.225E-03	3.578E-03	4.711E-03

  - **More pressure drop** (to assess sensitivity on HX pressure drop)
    - 1.5 times the simple heat exchanger

Parametric studies

- **Coolant velocity and temperature**
  - Design goals is to create prototypical PWR conditions inside the test section
  - From legacy RELAP5 models steady state runs

Plant	Core inlet T [K]	Core outlet T [K]	Lower core velocity [m/s]	Upper core velocity [m/s]
4-loop Westinghouse	559	593	5.50	5.27
3-loop Westinghouse	560	593	4.57	4.91
4-loop Westinghouse	567	600	4.66	5.06

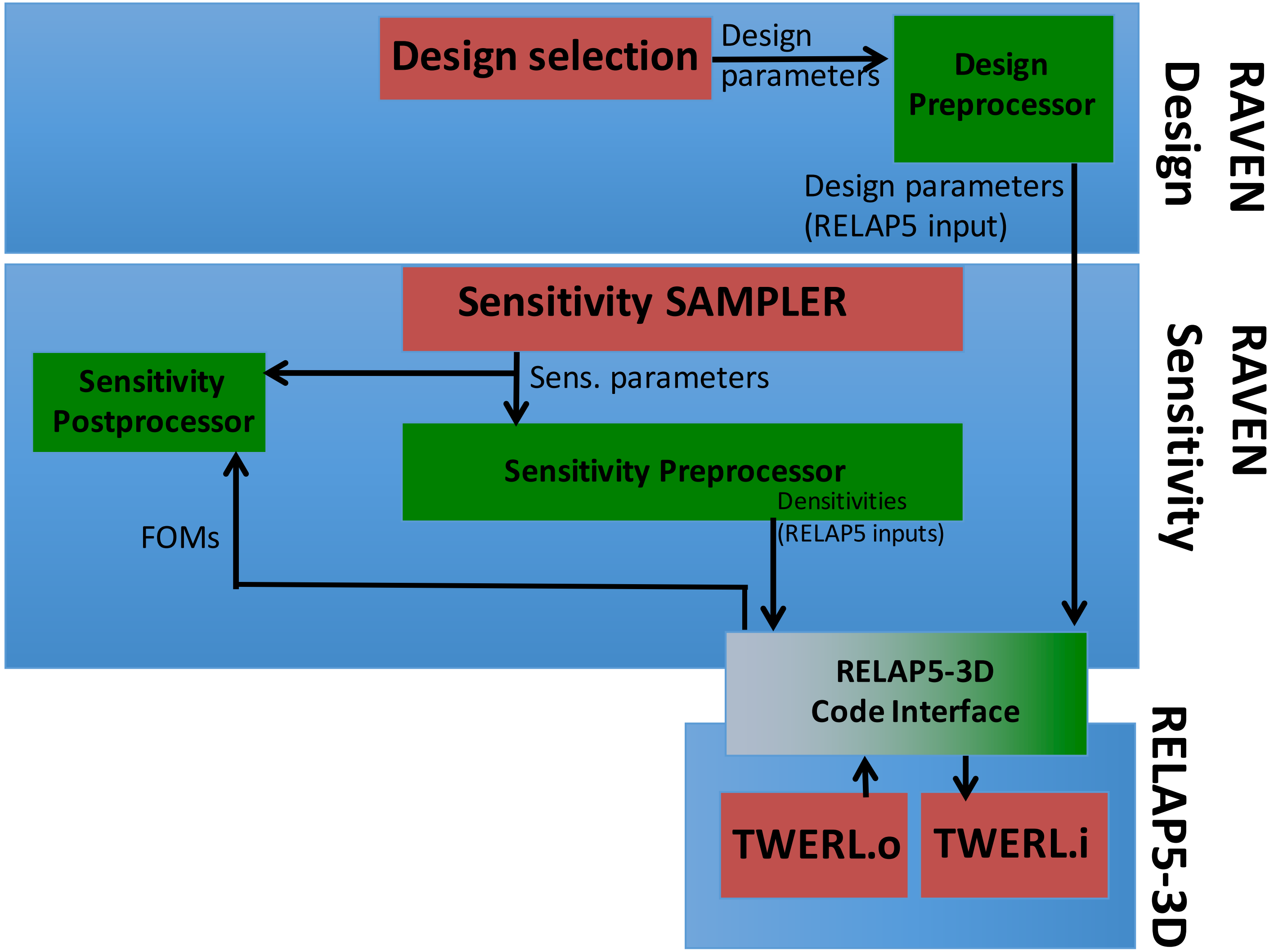
  - **Parametric for TWERL**
    - Test section fluid velocity: 4.9 and 5.3 [m/s].
    - Test section fluid temperature: 540, 560, 580 and 600 [K].

- **Wall roughness**
  - **Parametric for TWERL**
    - Wall roughness: 1.52E-6 (drawn tubing), 1.5E-5 and 4.6E-5 (commercial steel) [m].

RAVEN

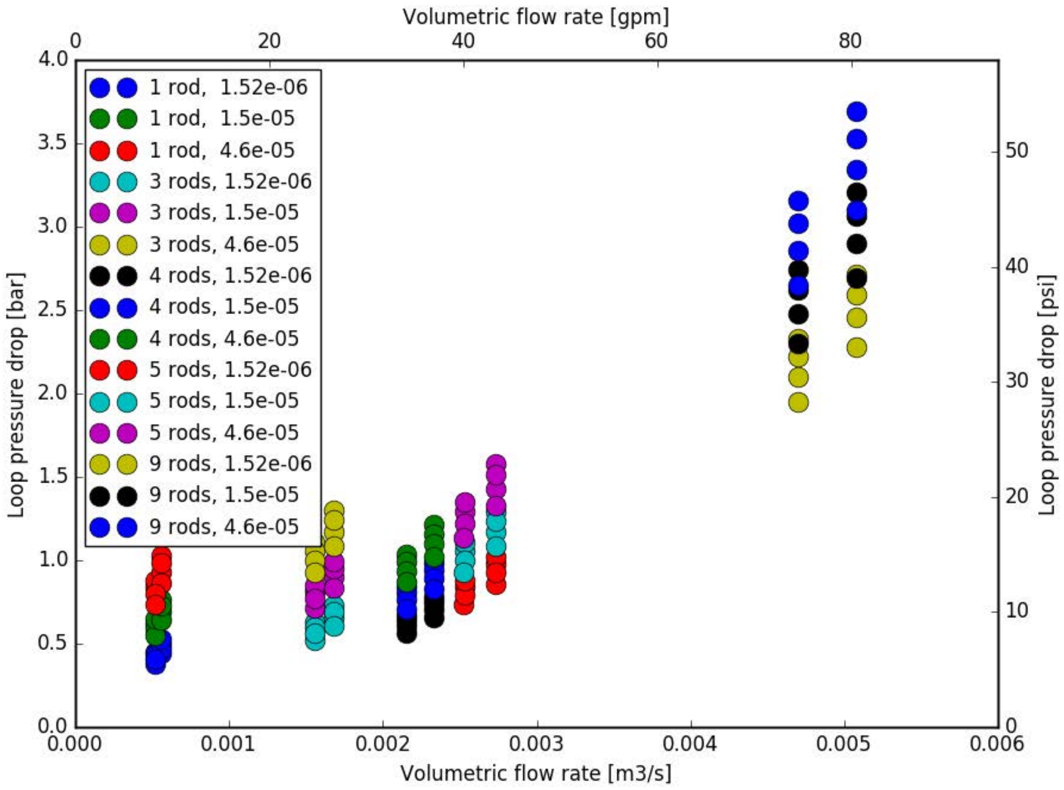
- **RAVEN**
  - Parametric and probabilistic analysis
  - **Workflow manager**
    - Input sampling
    - Running Model/Surrogate
    - Output post-processing
  - **Coupled** to RELAP5-3D

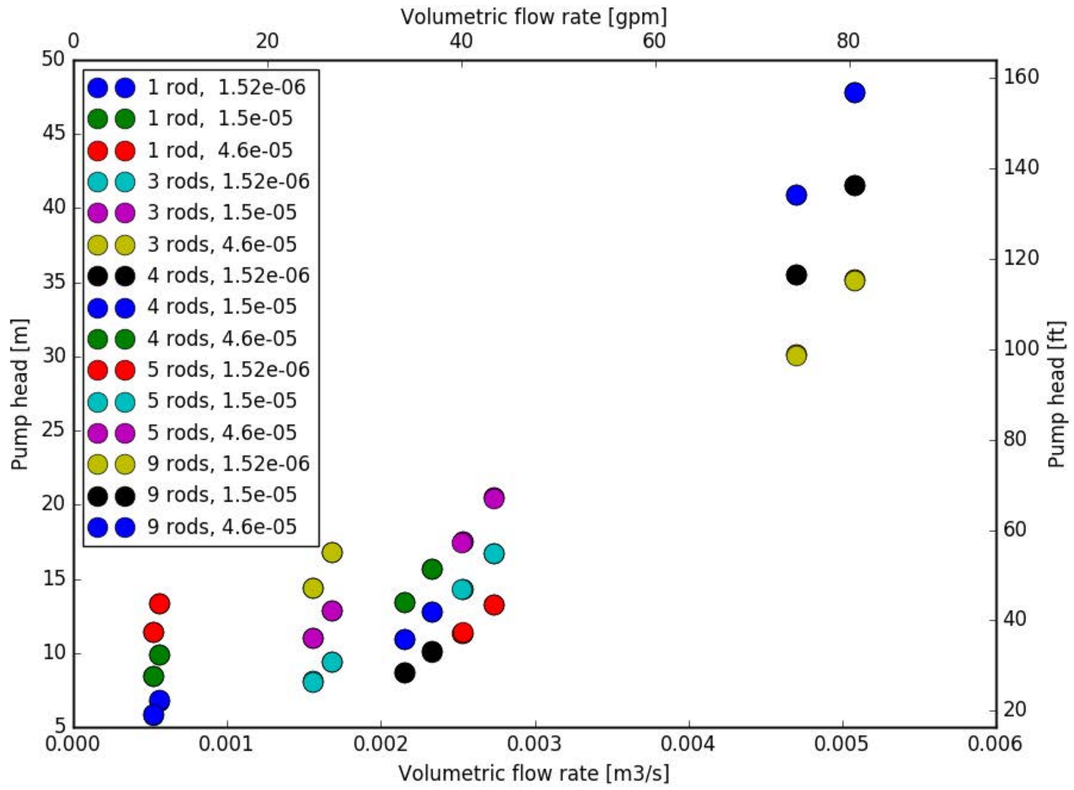
- Two layer "**RAVEN running RAVEN**" workflow for TWERL analysis



Results

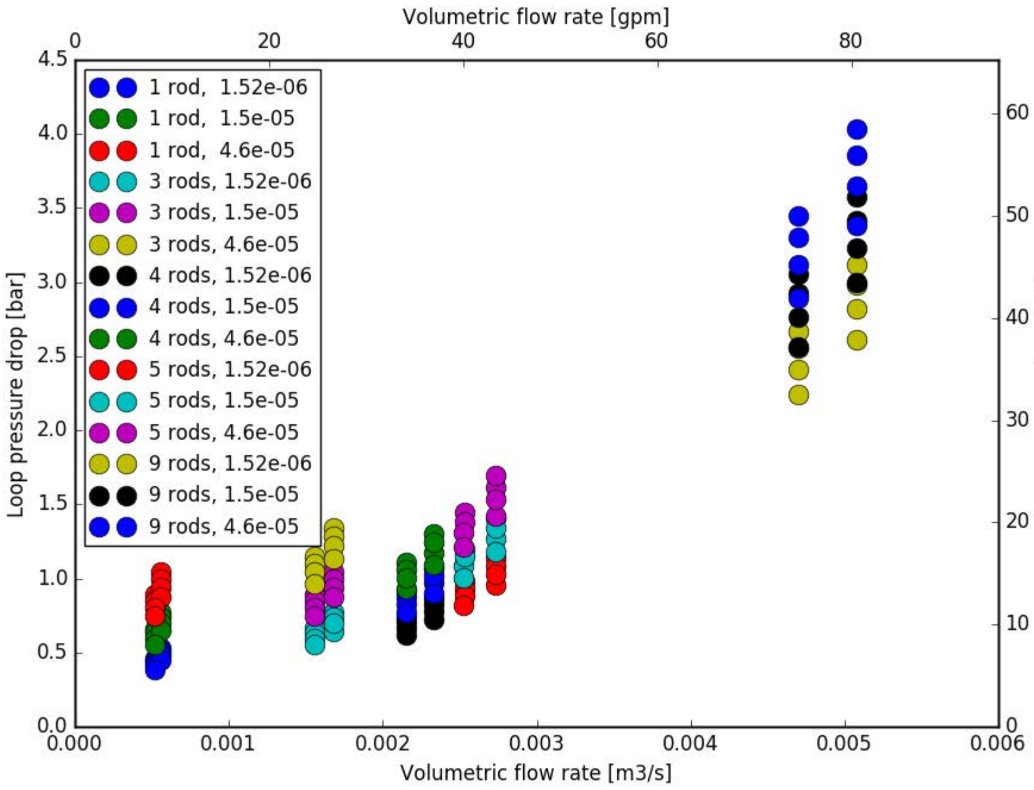
- Steady state, isothermal calculations, **no HX**

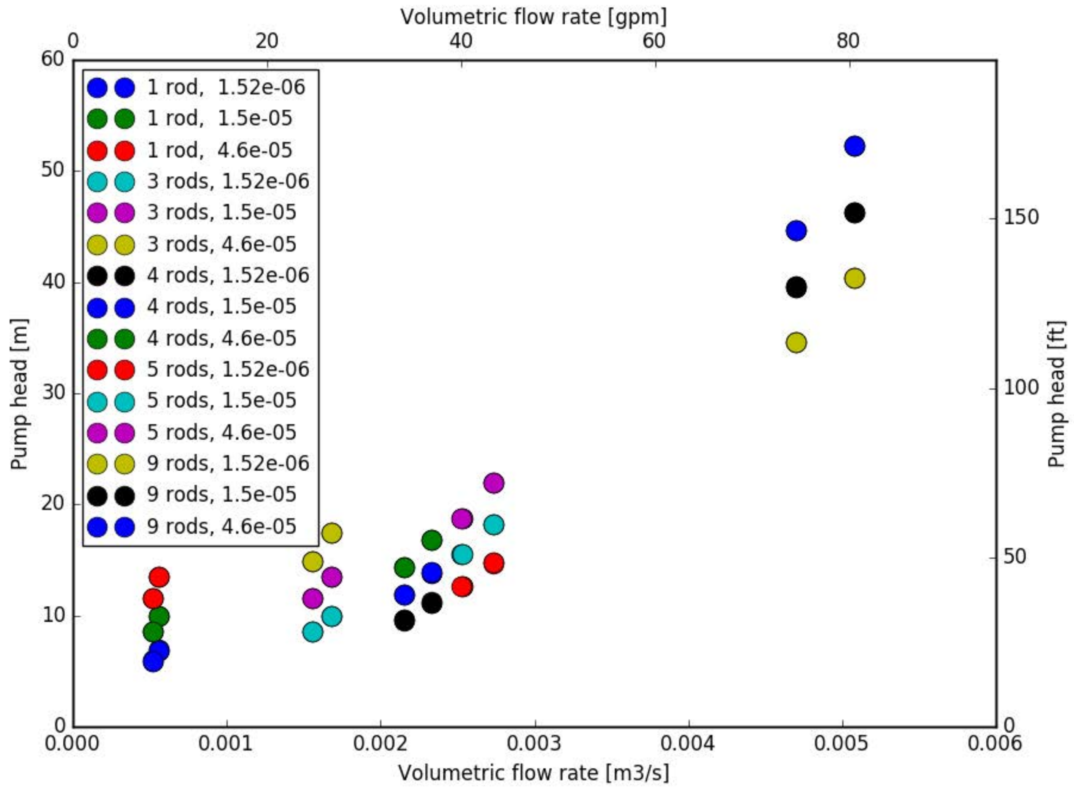




Results

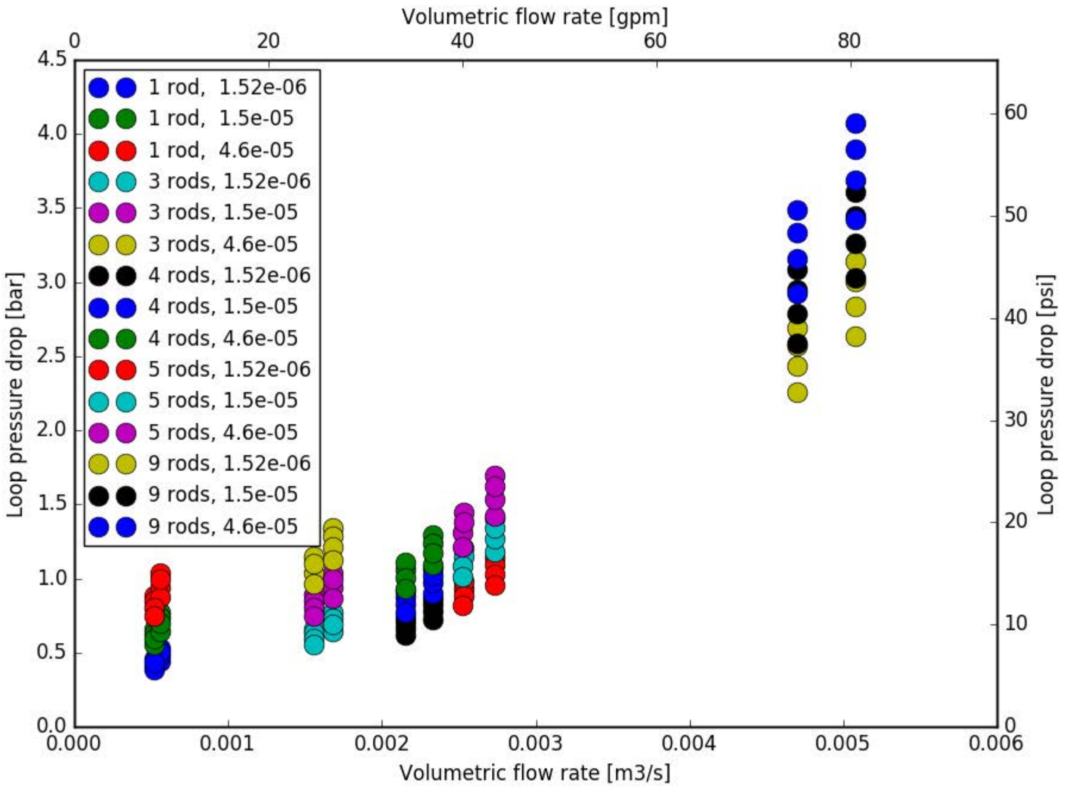
- Steady state, isothermal calculations, **Simple HX**

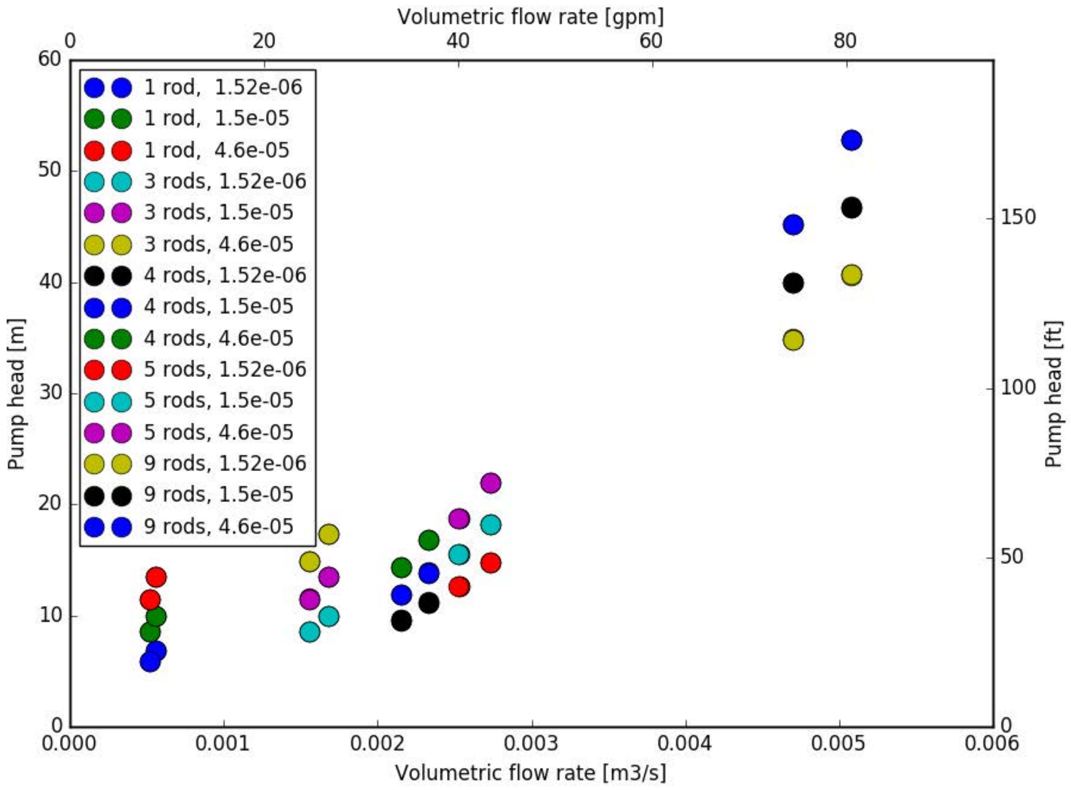




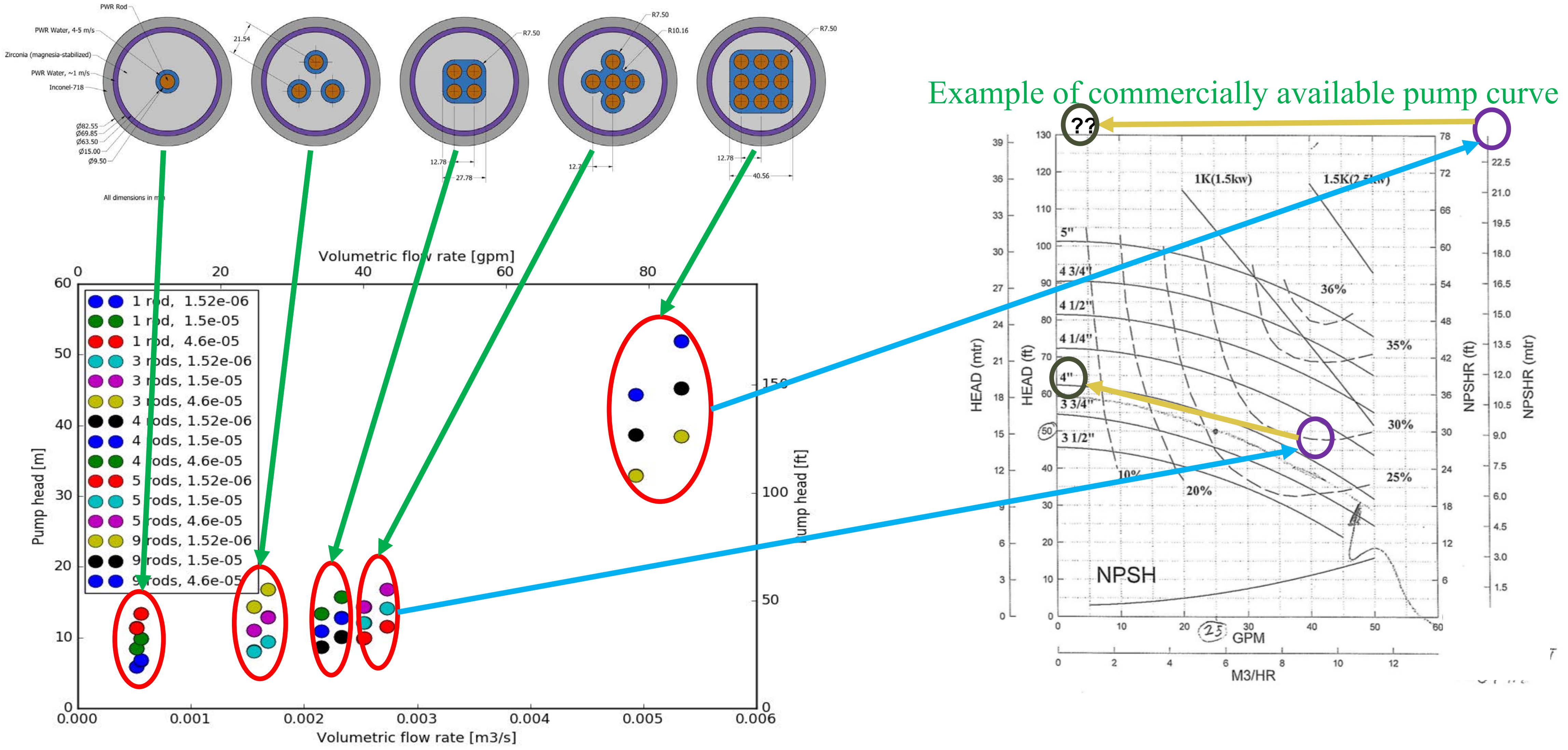
Results

- Steady state, isothermal calculations, **More HX**





Pump design



PWR Rod
PWR Water, 4-5 m/s
Zirconia (magnesia-stabilized)
PWR Water, ~1 m/s
Inconel-718
Ø82.55
Ø69.85
Ø63.50
Ø15.00
Ø9.50
All dimensions in mm
21.54
R7.50
12.78
27.78
R10.16
40.56
Volumetric flow rate [gpm]
Volumetric flow rate [m3/s]
Pump head [m]
Pump head [ft]
1 rod, 1.52e-06
1 rod, 1.5e-05
1 rod, 4.6e-05
3 rods, 1.52e-06
3 rods, 1.5e-05
3 rods, 4.6e-05
4 rods, 1.52e-06
4 rods, 1.5e-05
4 rods, 4.6e-05
5 rods, 1.52e-06
5 rods, 1.5e-05
5 rods, 4.6e-05
9 rods, 1.52e-06
9 rods, 1.5e-05
9 rods, 4.6e-05
Example of commercially available pump curve
??
1K(1.5kw)
1.5K(2.5kw)
5"
4 3/4"
4 1/2"
4 1/4"
4"
3 3/4"
3 1/2"
10%
20%
25%
30%
35%
36%
NPSH
HEAD (mtr)
HEAD (ft)
NPSHR (ft)
NPSHR (mtr)
GPM
M3/HR

Conclusions and Future Work

- Compact pump might be **able to drive multi-pin bundles**

- Need **more detailed information** on loop geometry
  - ⇒ **Heat exchanger** and **instrumentation** contributing most to the flow losses (after the test section)
  - ⇒ High pressure and temperature limiting for pump design (seal and motor coupling)
  - ⇒ Strat conversation with pump manufacturer for special design pump

- We are comparing TWERL RELAP5 results to representative PWR transient behavior using a statistical method measuring the **“representativity”** of the experiment.
  - Watch out for a presentation at **NURETH 2019.**

INL

Idaho National Laboratory