Transient **R**eactor **T**est **L**oop (TRTL) Model Development

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WORKING GROUP MEETING MARCH 2017
TASK 2 BREAKOUT SESSION
ARGONNE, ILLINOIS

Outline

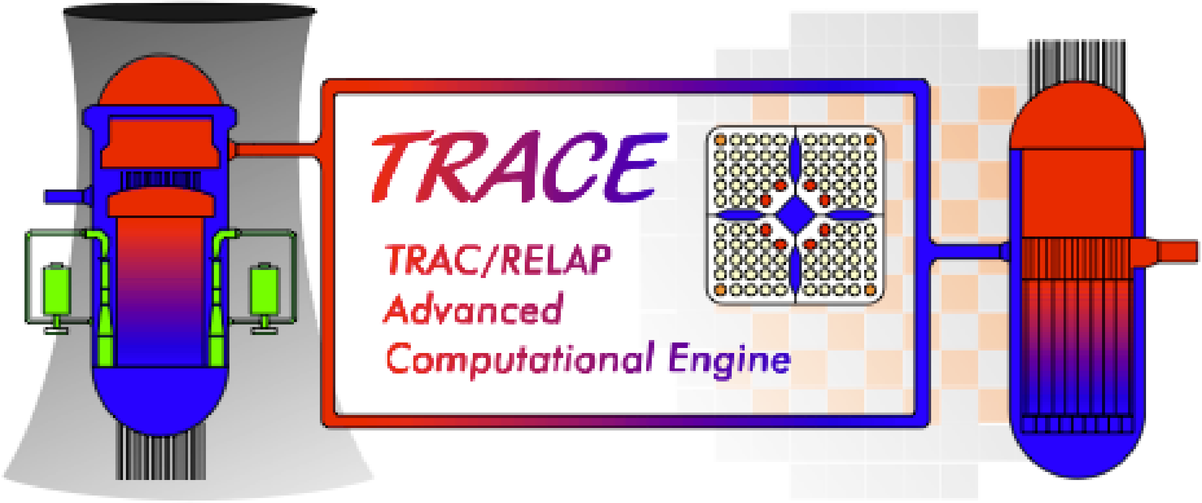
- Task Description
- Current Model Status
- Problem description report updates

- Brief introduction to research stemming from current task.

Task 2.2 Overview

Task #	Description	Owner
2.2	Water Loop	
2.2.1	Identify and review industry needs for water loop	W. Marcum
2.2.2	Develop loop technical and functional requirements	W. Marcum
2.2.3	Loop design	W. Marcum
2.2.4	Loop fabrication	J. Nylander
2.2.5	Loop shakedown	W. Marcum
2.2.6	Define flow loop 'operations tests' and 'benchmark tests'	W. Marcum
2.2.7	Operations test conduct	W. Marcum
2.2.8	Synthesis of operations tests data	W. Marcum
2.2.9	Benchmark test conduct	W. Marcum
2.2.10	Synthesis of benchmark test data	W. Marcum
2.2.11	Modeling of benchmark test with U.S. NRC code TRACE	C. Jensen
2.2.12	Modeling of benchmark test with RELAP5-3D	C. Jensen
2.2.13	Comparison of experimental data & model results for problem	C. Jensen
2.2.14	Benchmark level evaluation of problem	C. Jensen
2.2.15	Evaluation of uncertainties in selected problem	W. Marcum
2.2.16	Submission of benchmark for peer review	C. Jensen

Task 2.2.11: Modeling of benchmark test with TRACE



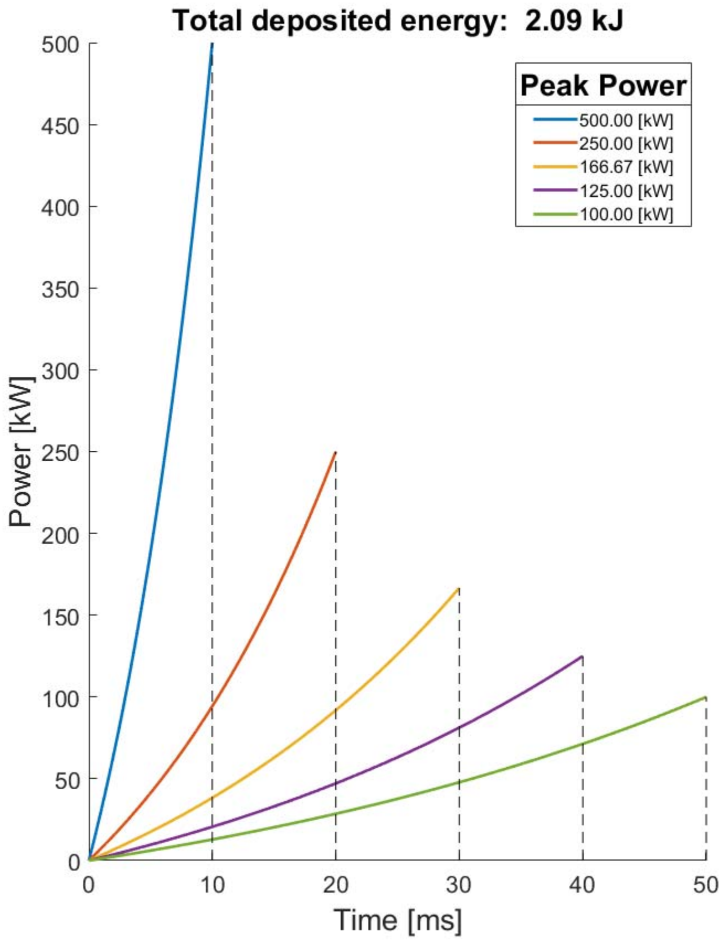
- OSU will develop a TRACE model for one of the benchmark tests performed using the U.S. NRC code TRACE. ***Modeling of the benchmark test will be done blindly,*** based on the design package put together as a part of task 2.2.3. The data will not be made available until the modeling and results have been completed.

TRTL Power Profile Calculator

```
What is the desired peak power? [kW]: 500
Enter an increasing array of desired Pulse
Lengths [ms]
    (ex. [10,20,100.5] )
: [10,20,30,40,50]

*------------------------------*
| Max Power      :  500.0 [kW] |
| Shortest Pulse:   10.0 [ms] |
| Energy Dep.    :  2.090 [kJ] |
*------------------------------*

 (1) P(t)=290.99*[exp(t/T)-1]
 (2) P(t)=145.49*[exp(t/T)-1]
 (3) P(t)= 97.00*[exp(t/T)-1]
 (4) P(t)= 72.75*[exp(t/T)-1]
 (5) P(t)= 58.20*[exp(t/T)-1]
```



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Problem Description Report

Will follow the same structure as Task 2.1's problem description report.

1. Facility Geometry Data
2. Material Data
3. Facility Instrumentation Plan
4. Initial and Boundary Conditions
5. Parameters of Interest
6. Specified Format for Submission of Results

Problem Description Report

Currently – Facility geometry data and material data.

Near Future – Initial and boundary conditions TBD. Determine parameters of interest.

Ultimately – Facility instrumentation plan. Verify "as built" geometry. Collect experimental data and submit to report.

Problem Description Report

Primary Loop

Component	Name	Diagram Pointer	length (m)	Volume (m^3)	Volume Avg Flow Area (m^2)	Volume Avg Flow Area (m^2)2	Wall Rougness (m)	Pressure (Pa)	Liquid Temp (K)	Vapor Temp (K)	Gas Volume Fraction	Edge	ID (m)	OD (m)	Flow Area (m^2)	HD (m)	Angle (rad)	K-Fact	Liquid Velocity (m/s)	Vapor Velocity (m/s)
10	Pump Outlet	1	0.09525	4.08506E-05	0.000428877	0.000428877	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.023368	0.000428877	0.023368	1.57079633		0	0
				4.08506E-05	0.000428877							2	0	0.023368	0.000428877	0.023368	1.57079633		0	0
20	Test Train Lower	2	0.1524	7.39498E-05	0.000485235	0.000506707	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.0254	0.000506707	0.0254	1.57079633		0	0
		3	0.02855	1.32493E-05	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	2	0	0.024308	0.000464075	0.024308	1.57079633		0	0
		4	0.016459	9.05747E-06	0.000550305	0.000550305	1.50E-05	1.55E+07	573.15	573.15	0	3	0	0.024308	0.000464075	0.024308	1.57079633	*****	0	0
		4	0.016459	7.61189E-06	0.000462476	0.000462476	1.50E-05	1.55E+07	573.15	573.15	0	4	0	0.028575	0.000641302	0.028575	1.57079633		0	0
		5	0.015875	3.44551E-06	0.00021704	0.00021704	1.50E-05	1.55E+07	573.15	573.15	0	5	0	0.019685	0.000304341	0.019685	1.57079633		0	0
		6	0.012646	1.72696E-06	0.000136562	0.000111159	1.50E-05	1.55E+07	573.15	573.15	0	6	0.009525	0.01524	0.000111159	0.005715	1.57079633		0	0
		7	0.635094	1.03549E-04	0.000163046	0.000163046	1.50E-05	1.55E+07	573.15	573.15	0	7	0.009525	0.017272	0.000163046	0.007747	1.57079633		0	0
				2.12590E-04	2.47874E-03							8	0.009525	0.017272	0.000163046	0.007747	1.57079633		0	0
21	Test Train Middle	8	0.604046	9.84872E-05	0.000163046	0.000163046	1.50E-05	1.55E+07	573.15	573.15	0	1	0.009525	0.017272	0.000163046	0.007747	1.57079633		0	0
				9.84872E-05	1.63046E-04							2	0.009525	0.017272	0.000163046	0.007747	1.57079633		0	0
22	Test Train Upper	9	0.024206	1.09567E-05	0.000452644	0.000452644	1.50E-05	1.55E+07	573.15	573.15	0	1	0.009525	0.017272	0.000163046	0.007747	1.57079633		0	0
		10	0.705794	5.78476E-04	0.000819611	0.000819611	1.50E-05	1.55E+07	573.15	573.15	0	2	0.012936	0.034798	0.000819611	0.021862	1.57079633		0	0
		11	0.024854	2.03706E-05	0.000819611	0.000819611	1.50E-05	1.55E+07	573.15	573.15	0	3	0.012936	0.034798	0.000819611	0.021862	1.57079633		0	0
		12	0.0635	8.30017E-05	0.001307114	0.000819611	1.50E-05	1.55E+07	573.15	573.15	0	4	0.012936	0.034798	0.000819611	0.021862	1.57079633	*****	0	0
												5	0.023266	0.053975	0.00186296	0.030709	1.57079633		0	0
30	Expansion Region	13	0.482194	8.98308E-04	0.00186296	0.00186296	1.50E-05	1.55E+07	573.15	573.15	0	1	0.023266	0.053975	0.00186296	0.030709	1.57079633		0	0
				8.98308E-04	0.00186296		1.50E-05	1.55E+07	573.15	573.15	0	2	0.023266	0.053975	0.00186296	0.030709	1.57079633		0	0
40	Return Bend	14	0.009589	4.85882E-06	0.000506707	0.000506707	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.0254	0.000506707	0.0254	0		0	0
		15	0.030163	1.46362E-05	0.000485235	0.000506707	1.50E-05	1.55E+07	573.15	573.15	0	2	0	0.0254	0.000506707	0.0254	0		0	0
		16	0.023432	1.08742E-05	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	3	0	0.024308	0.000464075	0.024308	0		0	0
		17	0.019768	9.17384E-06	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	4	0	0.024308	0.000464075	0.024308	0		0	0
		17	0.019768	9.17384E-06	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	5	0	0.024308	0.000464075	0.024308	-0.78539816		0	0
		17	0.019768	9.17384E-06	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	6	0	0.024308	0.000464075	0.024308	-0.78539816		0	0
		18	0.02855	1.32493E-05	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	7	0	0.024308	0.000464075	0.024308	-1.57079633		0	0
		19	0.017488	9.62374E-06	0.000550305	0.000550305	1.50E-05	1.55E+07	573.15	573.15	0	8	0	0.024308	0.000464075	0.024308	-1.57079633		0	0
		19	0.017488	9.62374E-06	0.000550305	0.000550305	1.50E-05	1.55E+07	573.15	573.15	0	9	0	0.028575	0.000641302	0.028575	-1.57079633		0	0
		20	0.02855	1.32493E-05	0.000464075	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	10	0	0.024308	0.000464075	0.024308	-1.57079633		0	0
				1.03637E-04	0.004877004		1.50E-05	1.55E+07	573.15	573.15	0	11	0	0.024308	0.000464075	0.024308	-1.57079633		0	0
50	Heat Exchanger	21	0.508	2.52285E-04	0.000496624	0.000496624	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.025146	0.000496624	0.025146	-1.57079633		0	0
												2	0	0.025146	0.000496624	0.025146	-1.57079633		0	0
60	Venturi	22	0.025304	1.47374E-05	0.000582414	0.000672647	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.025146	0.000496624	0.025146	-1.57079633		0	0
		23	0.030088	1.91516E-05	0.000636519	0.000601063	1.50E-05	1.55E+07	573.15	573.15	0	2	0	0.029265	0.000672647	0.029265	-1.57079633		0	0
		24	0.0127	4.24819E-06	0.000334503	0.000334503	1.50E-05	1.55E+07	573.15	573.15	0	3	0	0.027664	0.000601063	0.027664	-1.57079633		0	0
		25	0.0254	3.21557E-06	0.000126597	0.000126597	1.50E-05	1.55E+07	573.15	573.15	0	4	0	0.012696	0.000126597	0.012696	-1.57079633		0	0
		26	0.08219	2.34894E-05	0.000285793	0.000285793	1.50E-05	1.55E+07	573.15	573.15	0	5	0	0.012696	0.000126597	0.012696	-1.57079633		0	0
		27	0.026162	1.42680E-05	0.000545372	0.000609785	1.50E-05	1.55E+07	573.15	573.15	0	6	0	0.024809	0.000483402	0.024809	-1.57079633		0	0
				3.31395E-04	0.003007823		1.50E-05	1.55E+07	573.15	573.15	0	7	0	0.027864	0.000609785	0.027864	-1.57079633		0	0
70	Downcomer	28	1.029963	5.11504E-04	0.000496624	0.000496624	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.025146	0.000496624	0.025146	-1.57079633		0	0
		29	0.026873	1.41991E-05	0.000528379	0.000560784	1.50E-05	1.55E+07	573.15	573.15	0	2	0	0.025146	0.000496624	0.025146	-1.57079633		0	0
		30	0.095936	5.16757E-05	0.000538648	0.000516812	1.50E-05	1.55E+07	573.15	573.15	0	3	0	0.026721	0.000560784	0.026721	-1.57079633		0	0
		31	0.02855	1.39954E-05	0.000490207	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	4	0	0.025652	0.000516812	0.025652	-1.57079633		0	0
		32	0.017488	9.62374E-06	0.000550305	0.000550305	1.50E-05	1.55E+07	573.15	573.15	0	5	0	0.024308	0.000464075	0.024308	-1.57079633		0	0
		32	0.017488	9.62374E-06	0.000550305	0.000550305	1.50E-05	1.55E+07	573.15	573.15	0	6	0	0.028575	0.000641302	0.028575	-1.57079633		0	0
		33	0.023917	1.11574E-05	0.000466504	0.000464075	1.50E-05	1.55E+07	573.15	573.15	0	7	0	0.024308	0.000464075	0.024308	-1.57079633		0	0
		34	0.291819	1.36845E-04	0.000468937	0.000468937	1.50E-05	1.55E+07	573.15	573.15	0	8	0	0.024435	0.000468937	0.024435	-1.57079633		0	0
		35	0.059847	2.80645E-05	0.000468937	0.000468937	1.50E-05	1.55E+07	573.15	573.15	0	9	0	0.024435	0.000468937	0.024435	-1.57079633		0	0
		36	0.194228	9.10807E-05	0.000468937	0.000468937	1.50E-05	1.55E+07	573.15	573.15	0	10	0	0.024435	0.000468937	0.024435	0		0	0
		37	0.059847	2.80645E-05	0.000468937	0.000468937	1.50E-05	1.55E+07	573.15	573.15	0	11	0	0.024435	0.000468937	0.024435	0		0	0
		38	0.120158	5.63465E-05	0.000468937	0.000468937	1.50E-05	1.55E+07	573.15	573.15	0	12	0	0.024435	0.000468937	0.024435	-1.57079633		0	0
		39	0.076198	5.94399E-05	0.000780071	0.000468937	1.50E-05	1.55E+07	573.15	573.15	0	13	0	0.024435	0.000468937	0.024435	-1.57079633		0	0
		40	0.117591	1.34065E-04	0.001140092	0.001140092	1.50E-05	1.55E+07	573.15	573.15	0	14	0	0.0381	0.001140092	0.0381	3.14159265		0	0
				1.15568E-03	0.007885821							15	0	0.0381	0.001140092	0.0381	3.14159265		0	0
90	Pump Internals		0.0238125	1.02126E-05	0.000428877	0.000428877	1.50E-05	1.55E+07	573.15	573.15	0	1	0	0.023368	0.000428877	0.023368	3.14159265		0	0
			0.0238125	1.02126E-05	0.000428877	0.000428877	1.50E-05	1.55E+07	573.15	573.15	0	2	0	0.023368	0.000428877	0.023368	3.14159265		0	0
			0.245528	1.05301E-04	0.000428877	0.000428877	1.50E-05	1.55E+07	573.15	573.15	0	3	0	0.023368	0.000428877	0.023368	1.57079633		0	0
												4	0	0.023368	0.000428877	0.023368	1.57079633		0	0
					Calculated	TRUE									Calculated	Calculated				

Secondary Loop

Component			length (m)	Volume (m^3)	Volume Avg Flow Area (m^2)	Volume Avg Flow Area (m^2)2	Wall Rougness (m)	Pressure (Pa)	Liquid Temp (K)	Vapor Temp (K)	Gas Volume Fraction	Edge	ID (m)	OD (m)	Flow Area (m^2)	HD (m)	Angle (rad)	K-Fact	Liquid Velocity (m/s)	Vapor Velocity (m/s)
250	HX Secondary Flow		0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	1	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	2	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	3	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	4	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	5	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	6	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	7	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	8	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	9	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.045085			0.000437225	1.50E-05	1.55E+06	430	430	0	10	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0
			0.45085									11	0.033401	0.040894	0.000437225	0.007493	1.57079633		0	0

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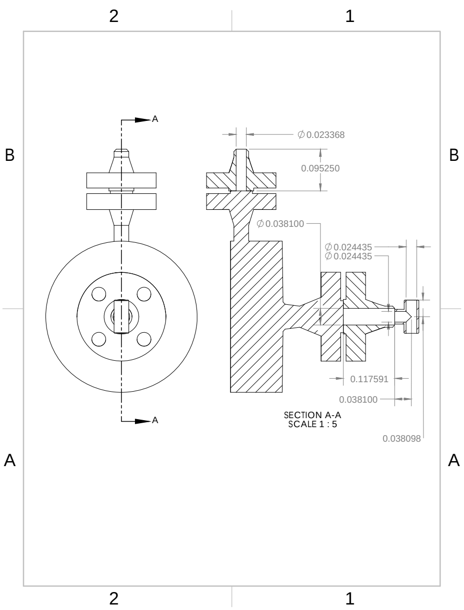
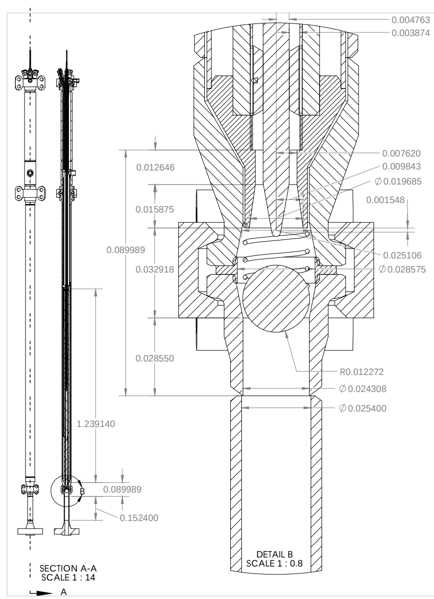
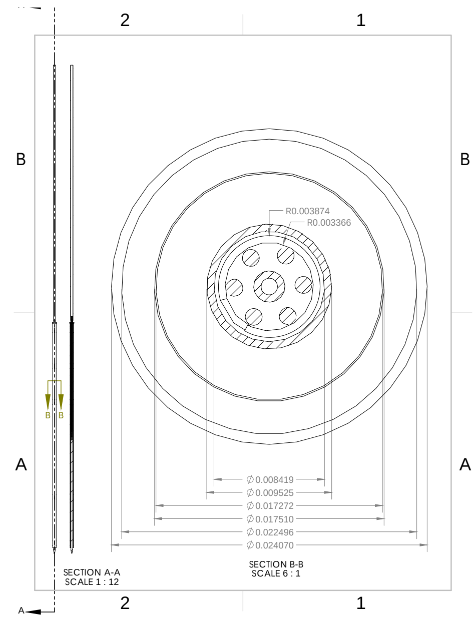
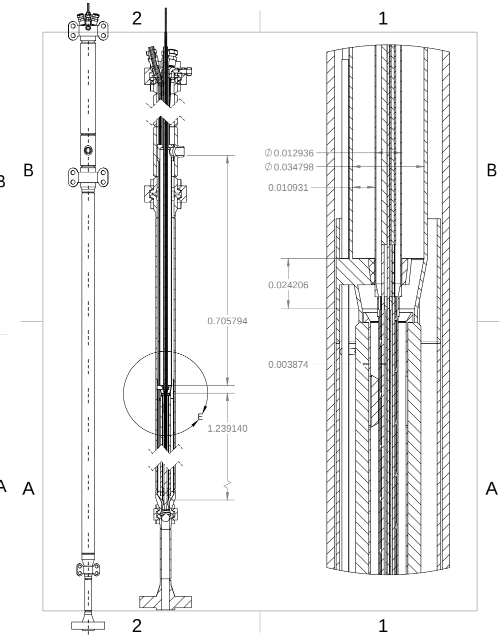
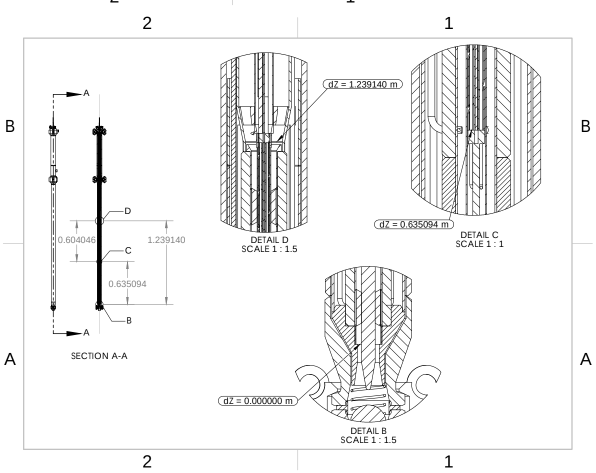
Problem Description Report

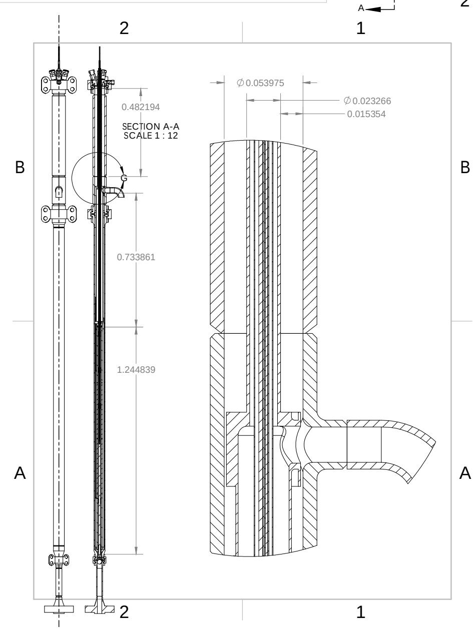


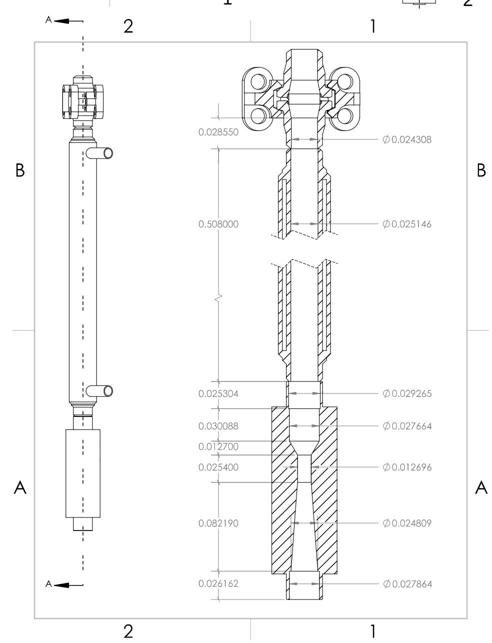












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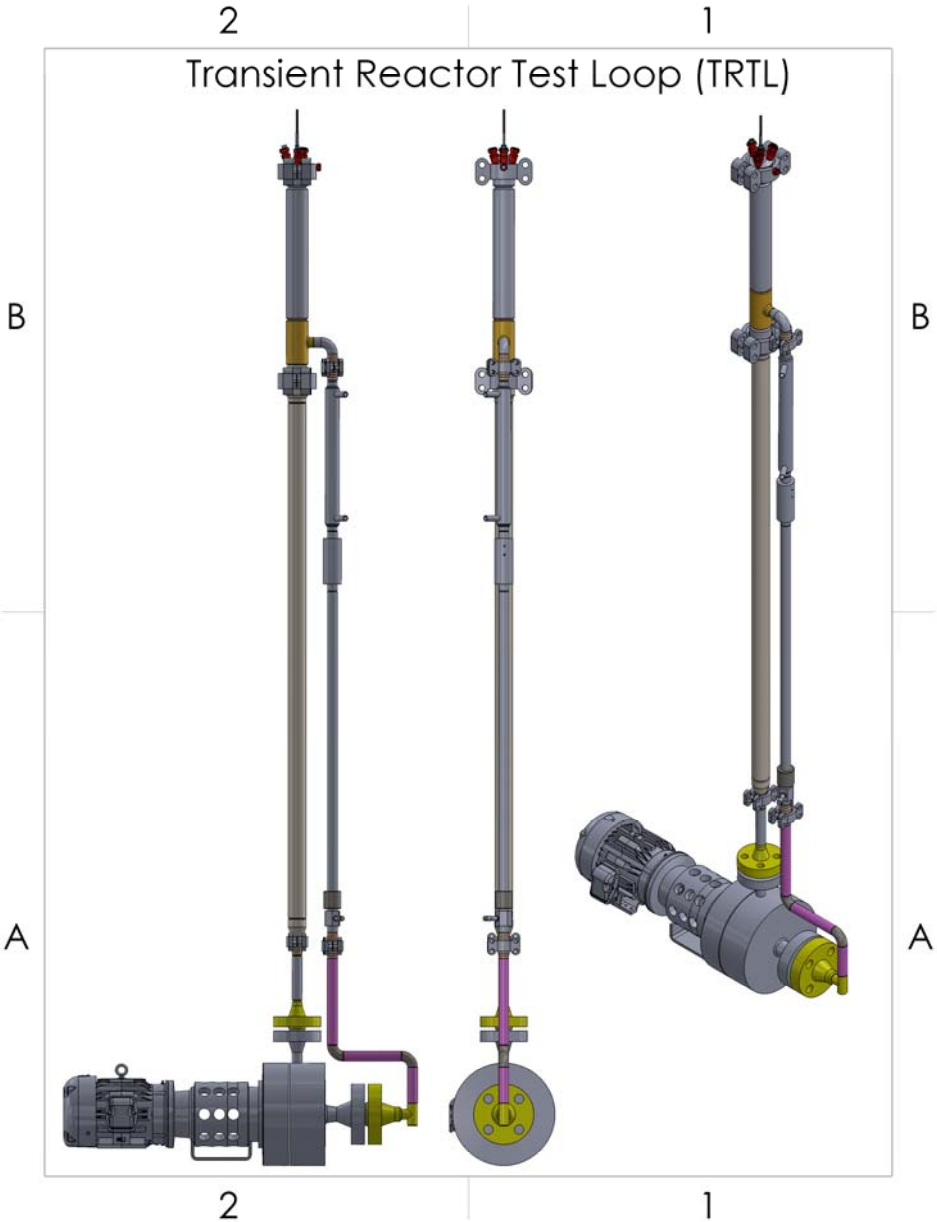
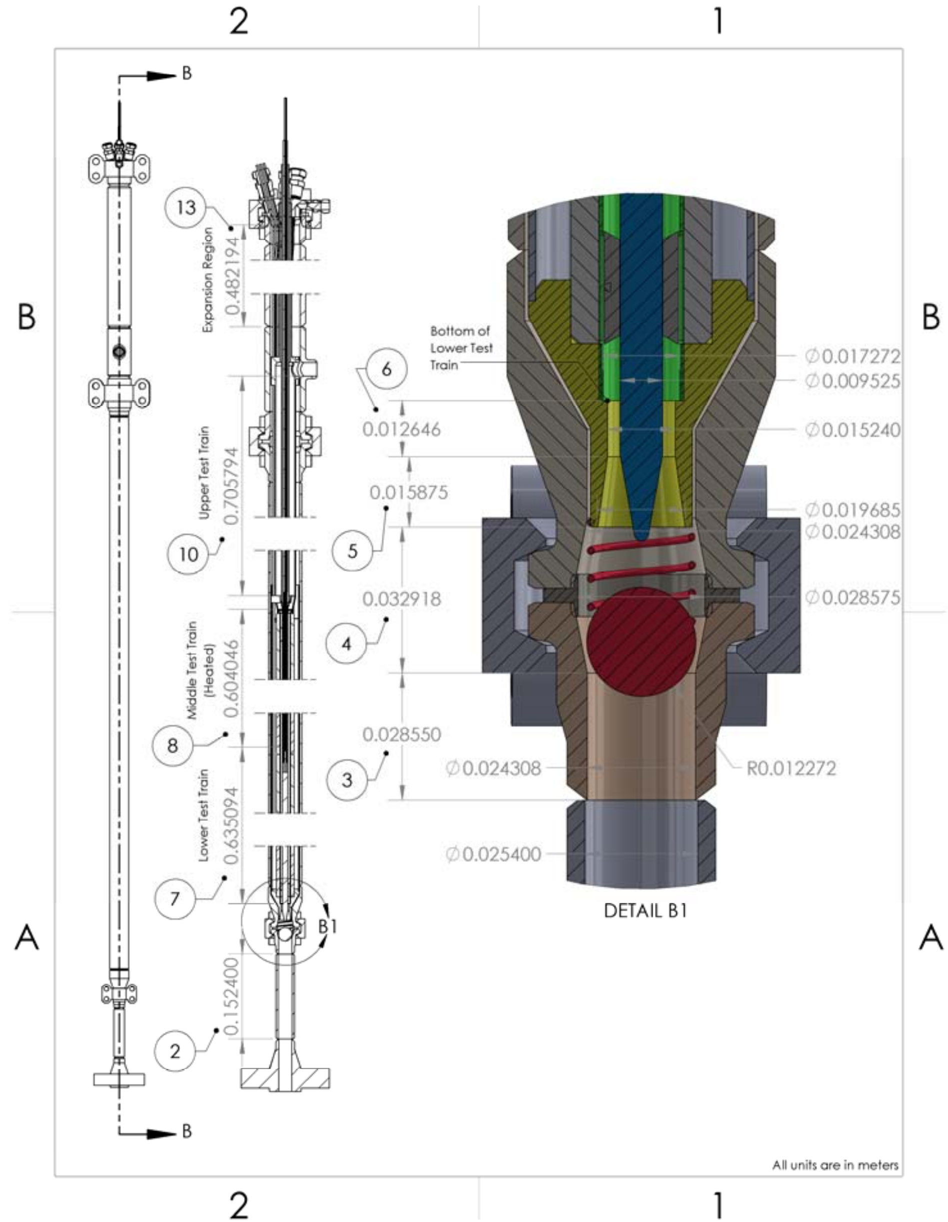
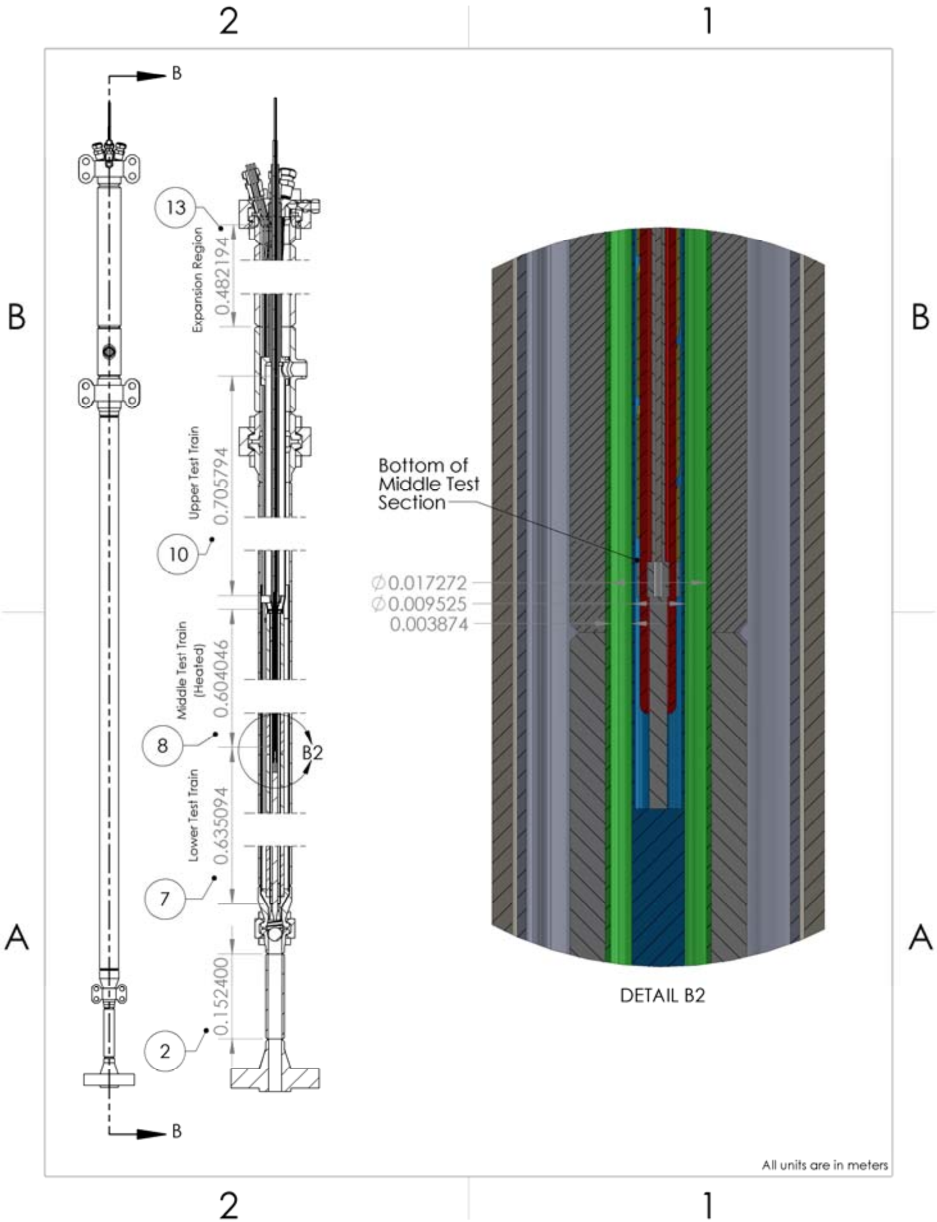
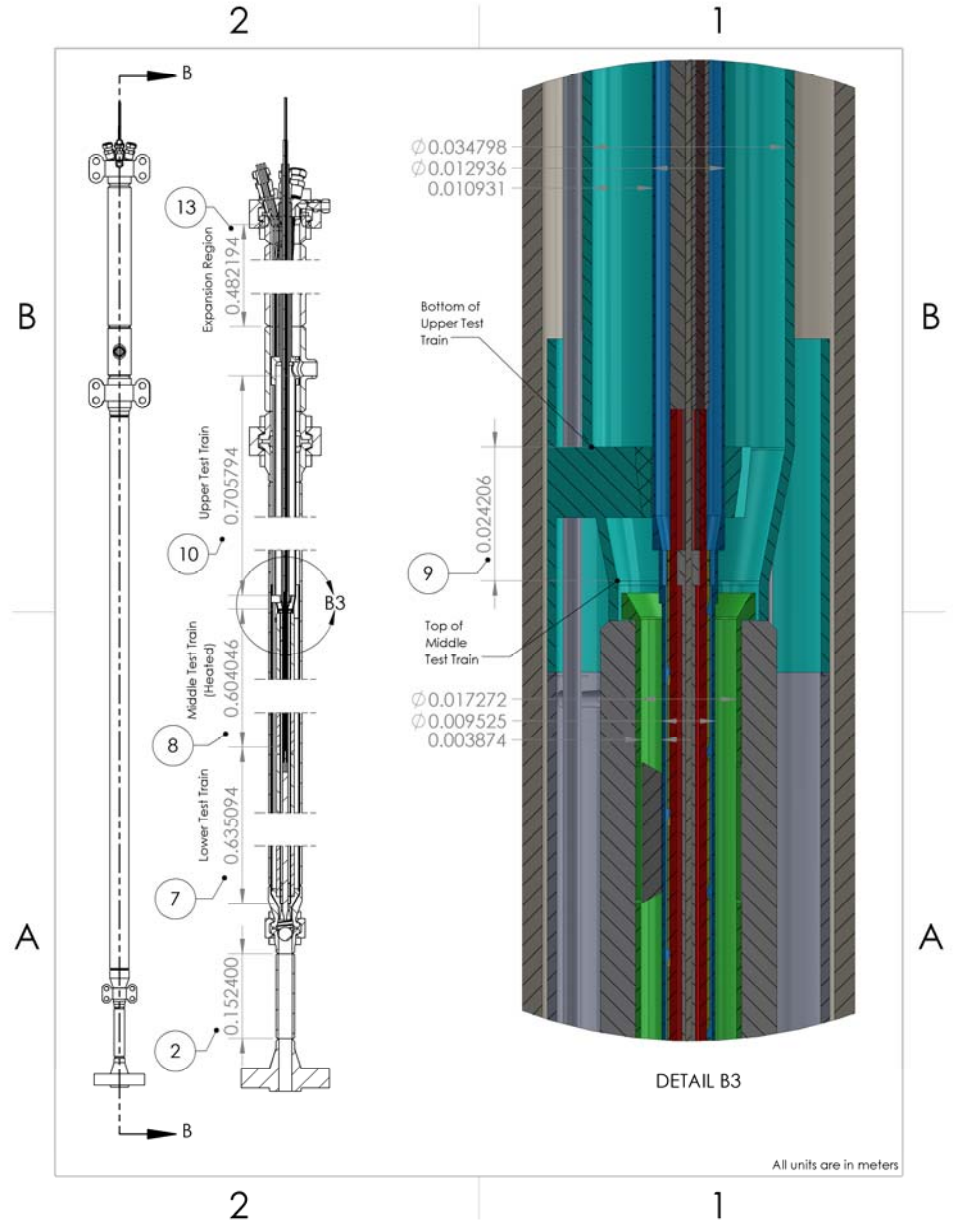
Problem Description Report: Updated



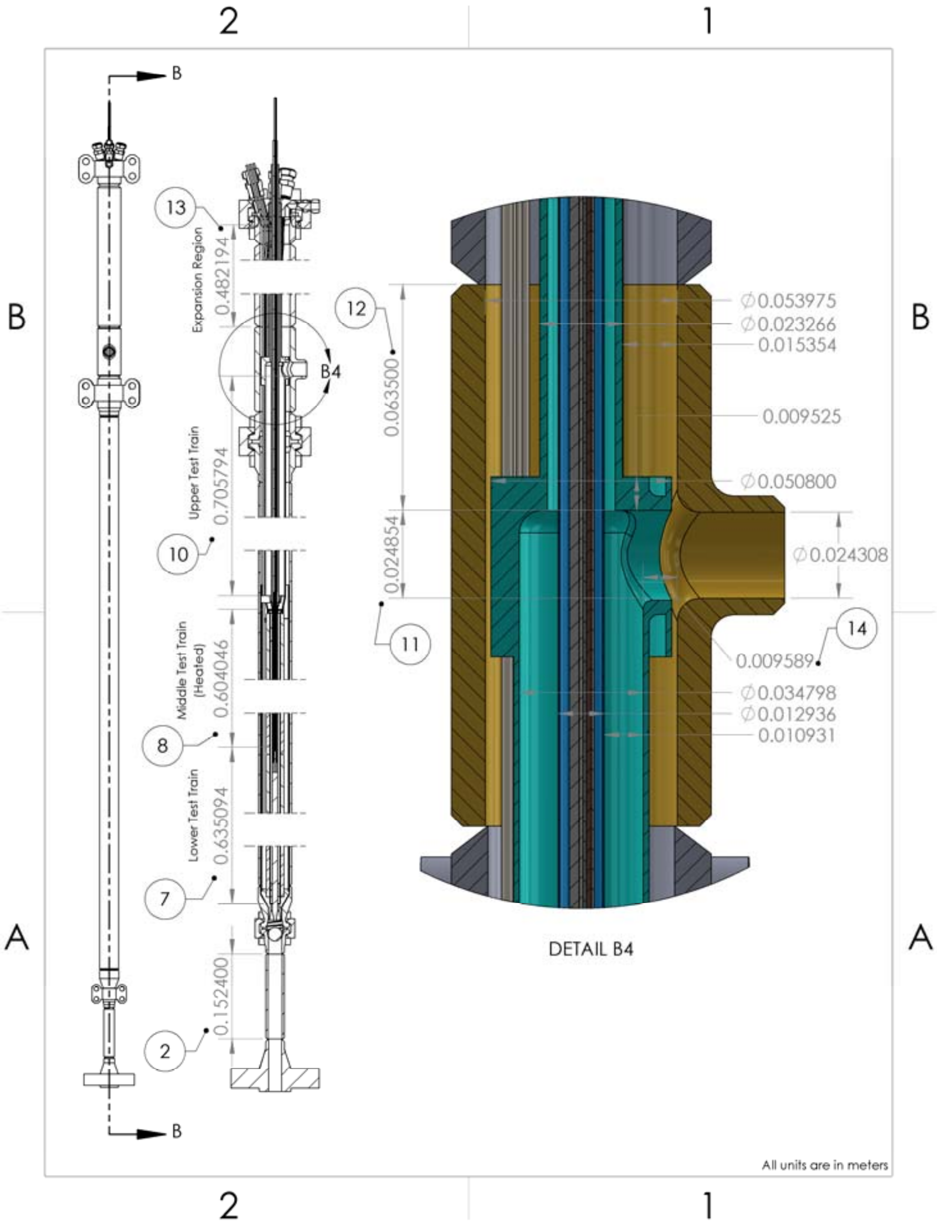


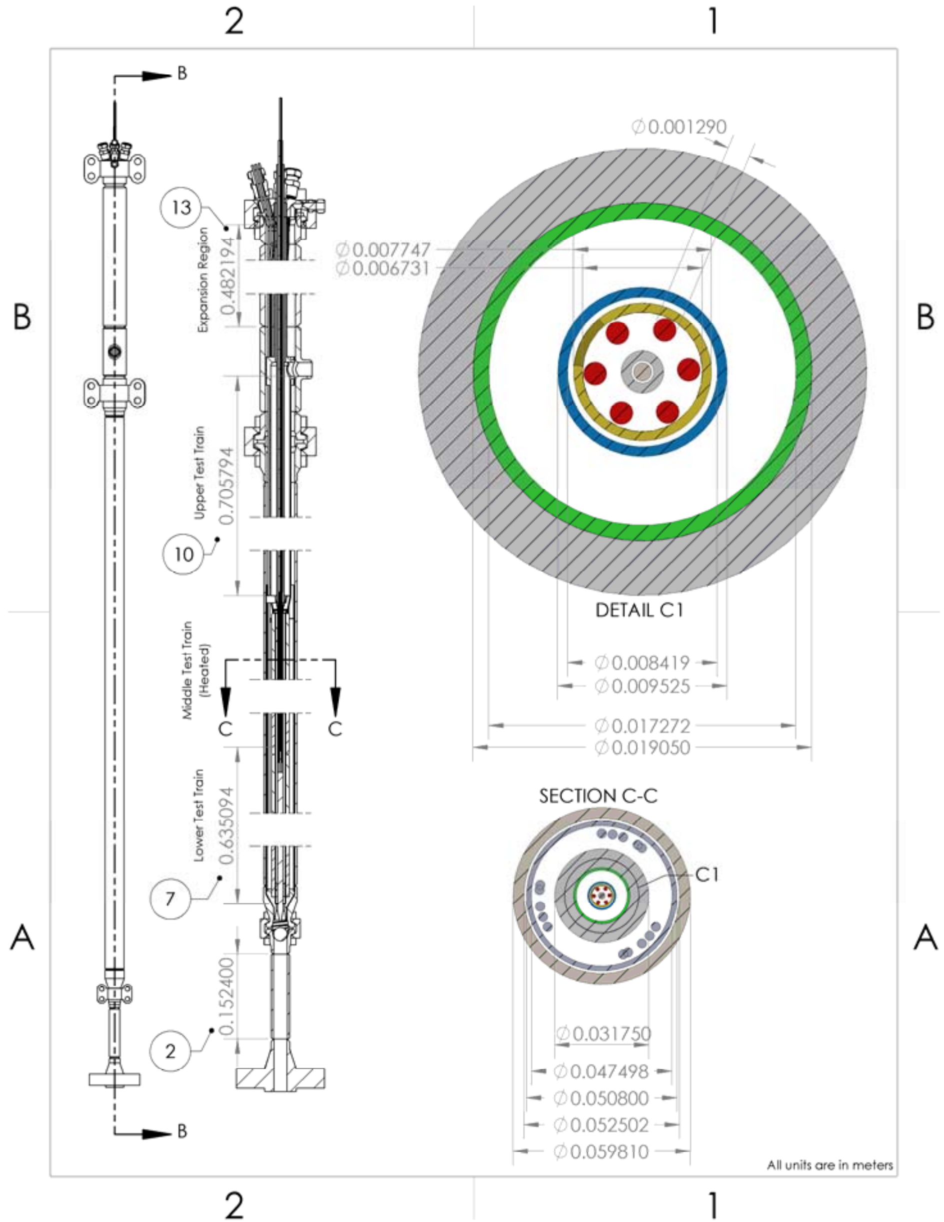
Problem Description Report: Updated



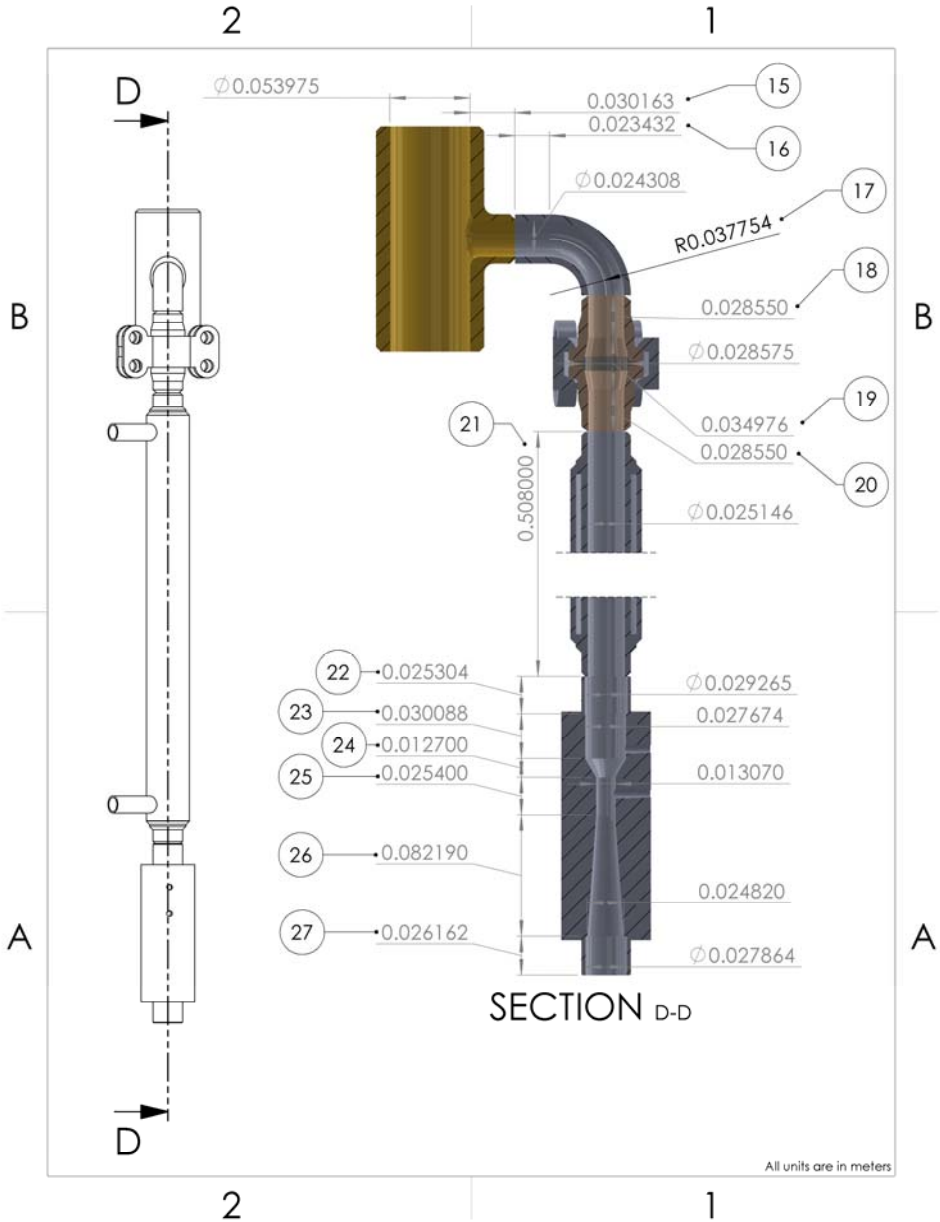


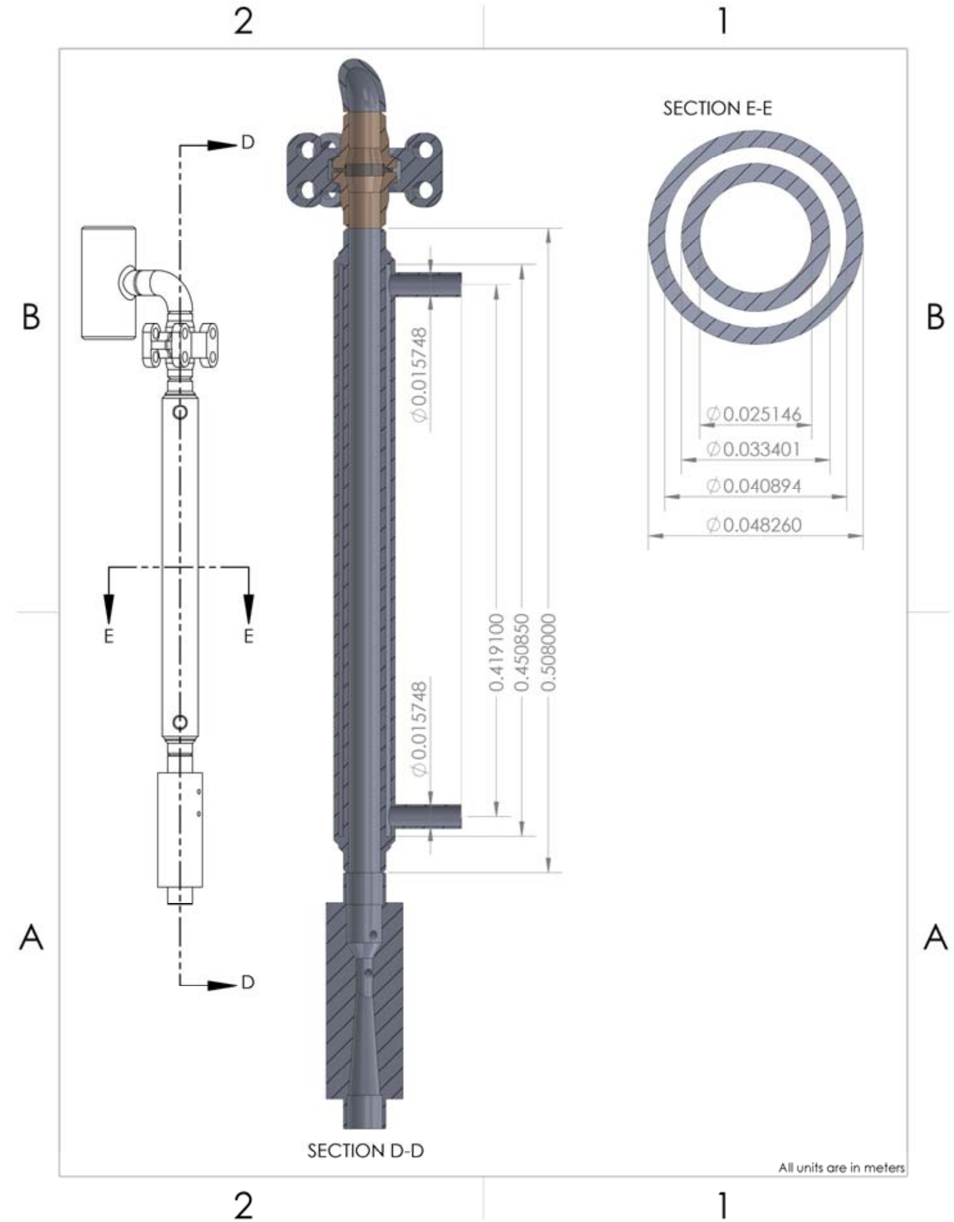
Problem Description Report: Updated



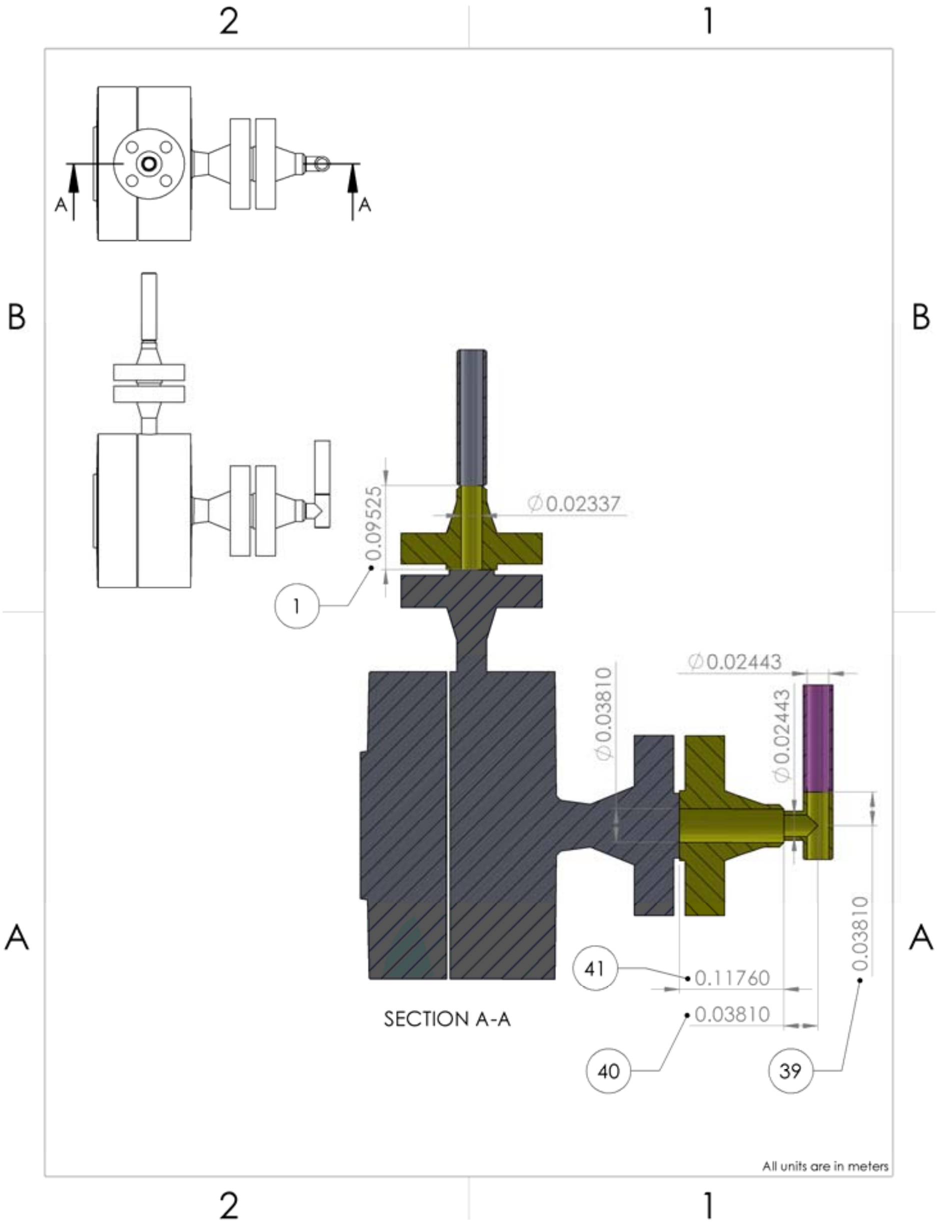


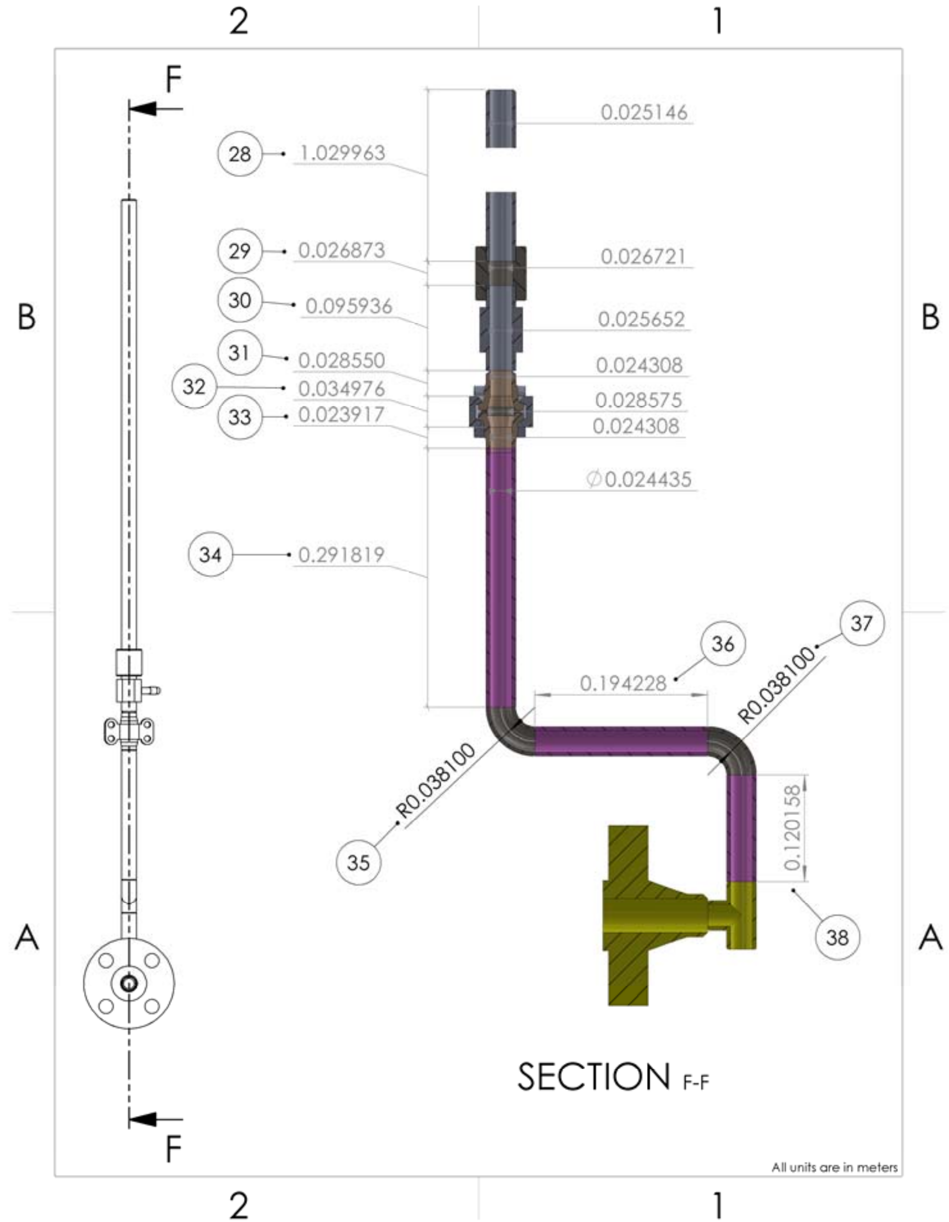
Problem Description Report: Updated





Problem Description Report: Updated





Studying the range of applicability of both quasi-steady state and transient CHF models.

Emory Brown

WORKING GROUP MEETING MARCH 2017
TASK 2 BREAKOUT SESSION
ARGONNE, ILLINOIS

Current approach to CHF Prediction

- Most studies investigate the trigger mechanism for CHF assuming an established two-phase flow system

- What about direct to film boiling CHF?

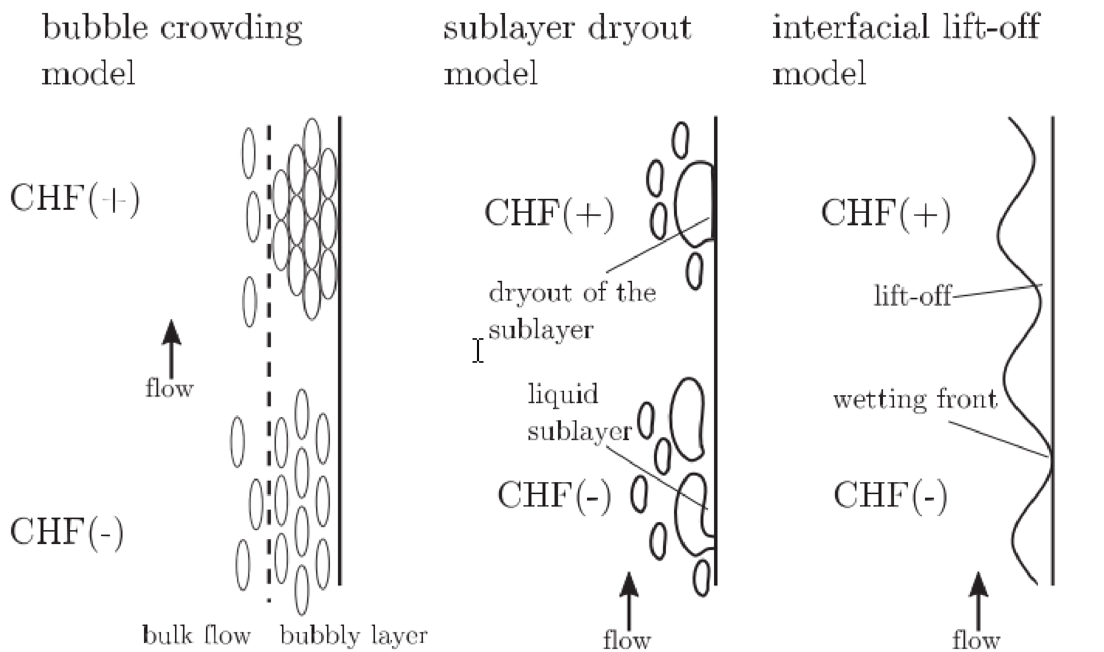


Fig. 1. Main trigger mechanisms for the CHF transition from the different mechanistic models (adapted from Konishi et al. [22]). [1]

Kemal Pasamehmetoglu - 1990

Developed robust quasi-steady state CHF model that switches from a hydrodynamic model to a film evaporation model to bridge the relevant phenomena

Does not capture phenomena associated with bubble incipience.

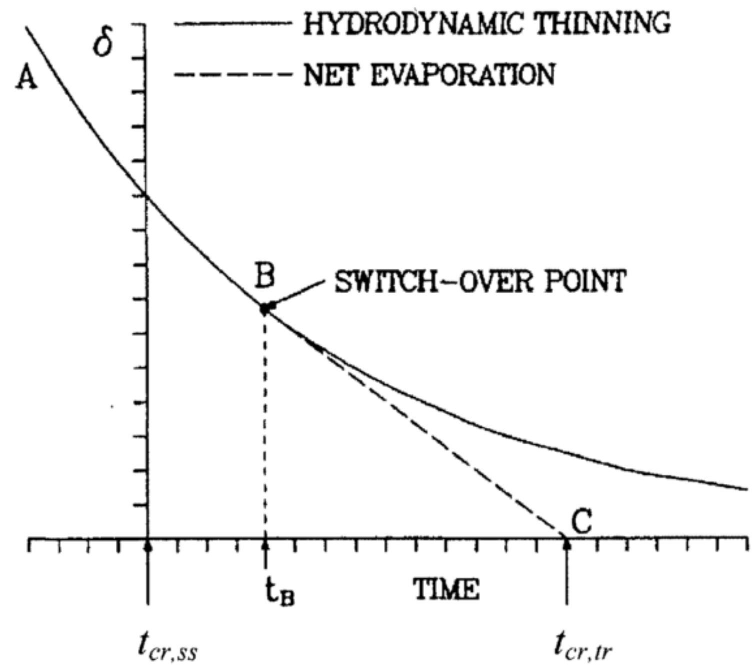


Figure 2.2, Switch-over point between hydrodynamic instability thinning and thermal thinning models for the liquid film (Pasamehmetoglu[2] et al. 1990b) [2]

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Kemal’s Model

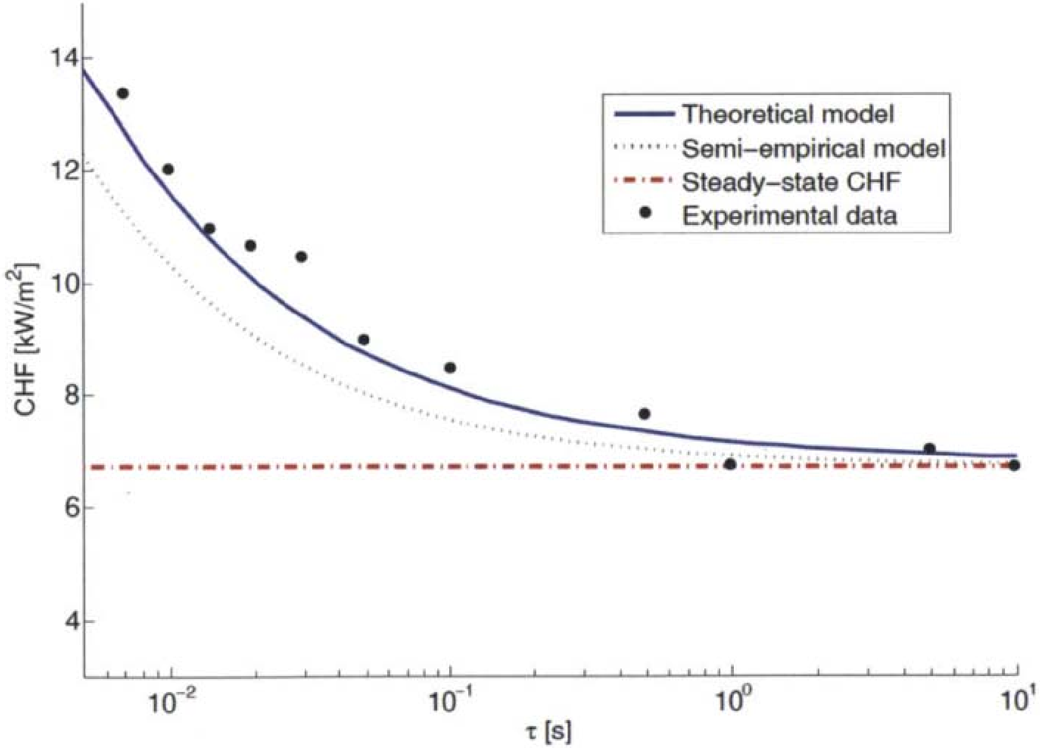


Figure 2.6, Comparison between transient critical heat flux determined with the theoretical and the semi-empirical models, the steady state critical heat flux, and the experimental data from Kataoka et al. (1983), for 10K subcooling, flow velocity of 1.35 m/s, and pressure of 1.503 MPa

Sakurai (2000)

- Studied direct to film boiling CHF.
- Original observations dependent on pre-pressurization and surface conditioning.

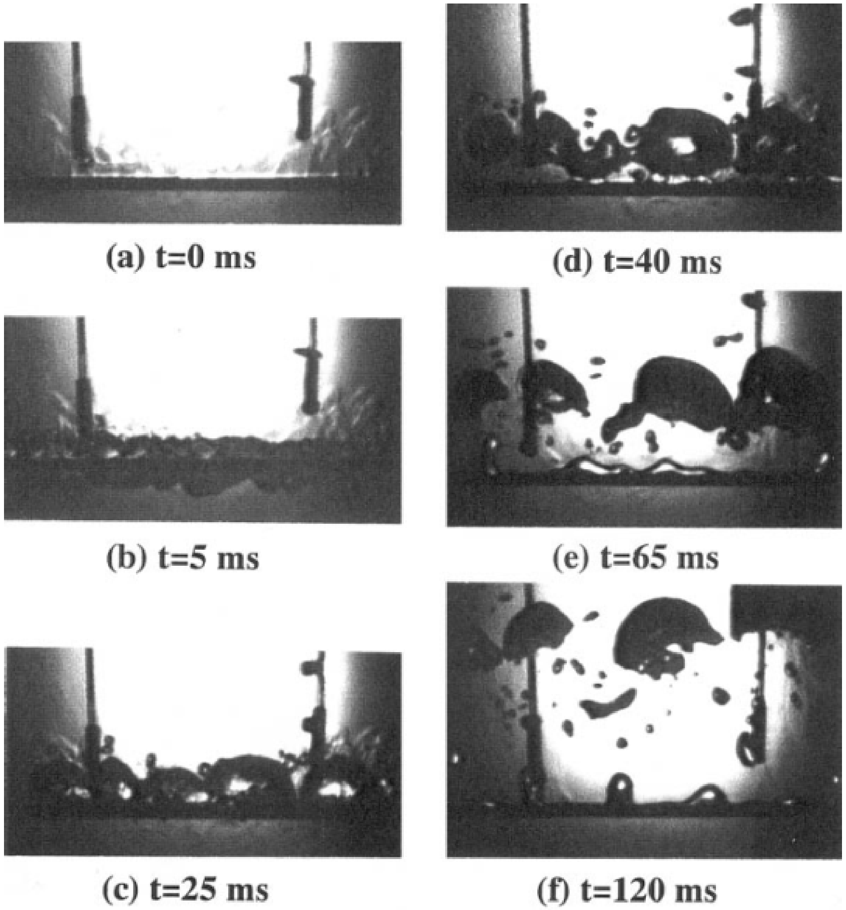


Fig. 52. Photographs of vapor film behavior during direct transition to film boiling caused by exponential heat input with $\tau = 1$ s to a 1.2-mm diameter cylinder at atmospheric pressure in liquid nitrogen. [3]

Sakurai (2000)

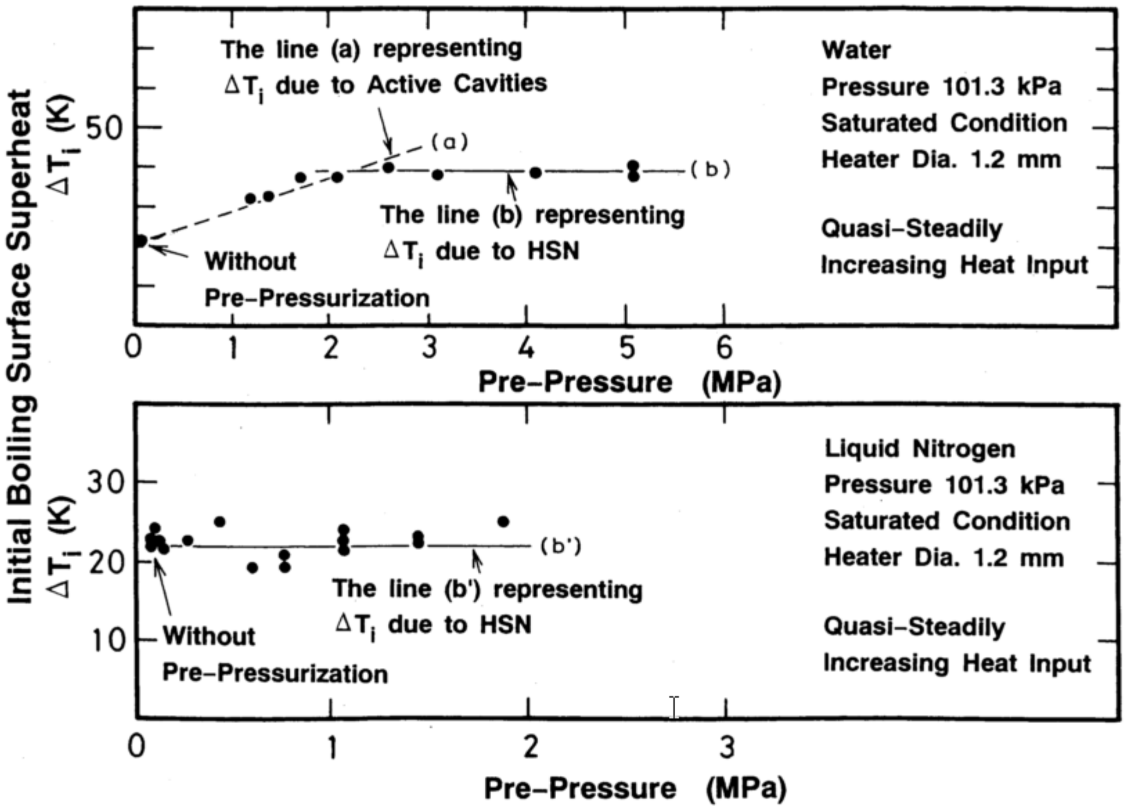


Fig. 1. Incipient boiling superheat vs. pre-pressure for water and liquid nitrogen. [2]

Sakurai (2000)

- Heterogeneous Spontaneous Nucleation
  - Direct to film boiling from flooded cavities
  - Has **lower** CHF than that predicted by quasi-steady state HI model
  - With increasing rate of heat input, HSN is observed even for non-pre-pressure depending on heat input, subcooling, and pressure.
  - The author states that HSN is also dependent on surface conditions.

Comparison of Models

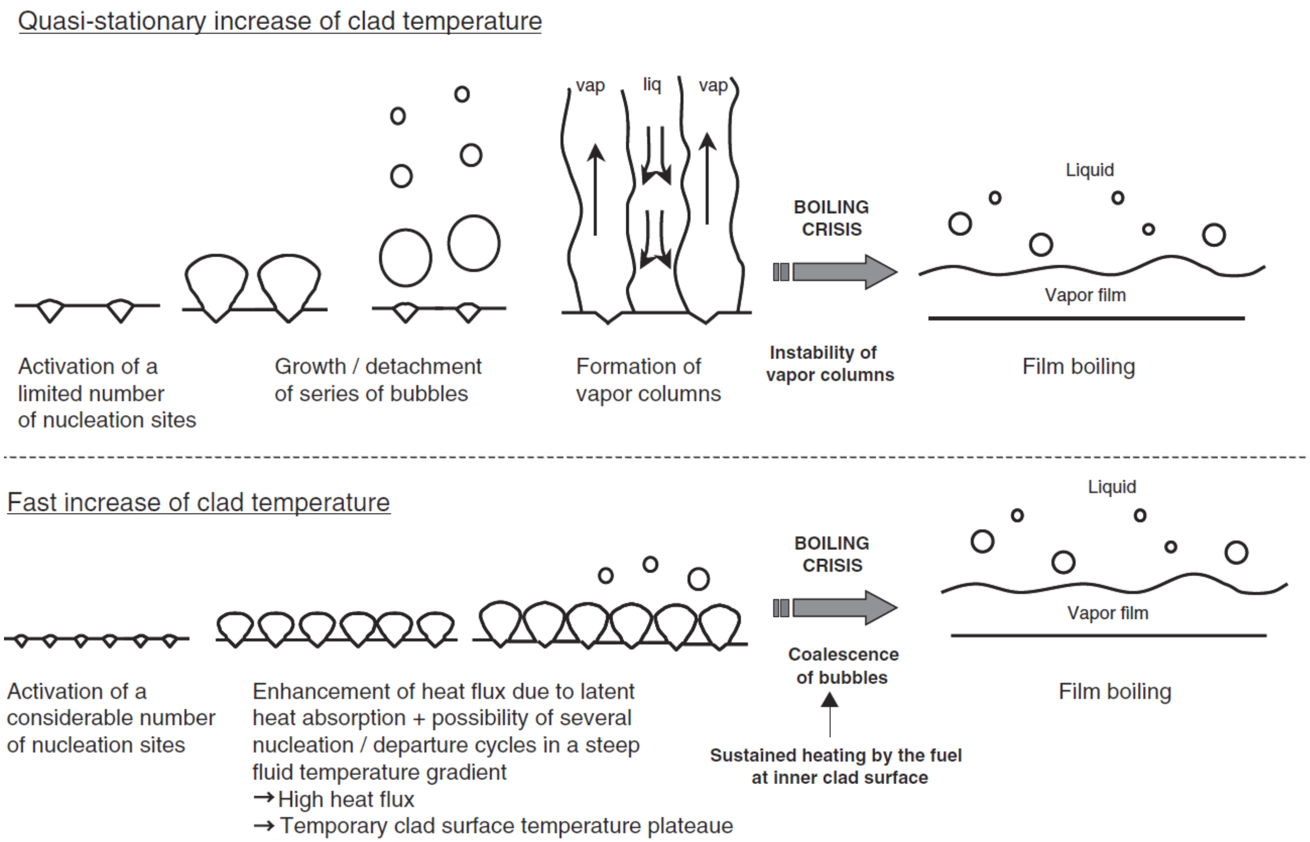
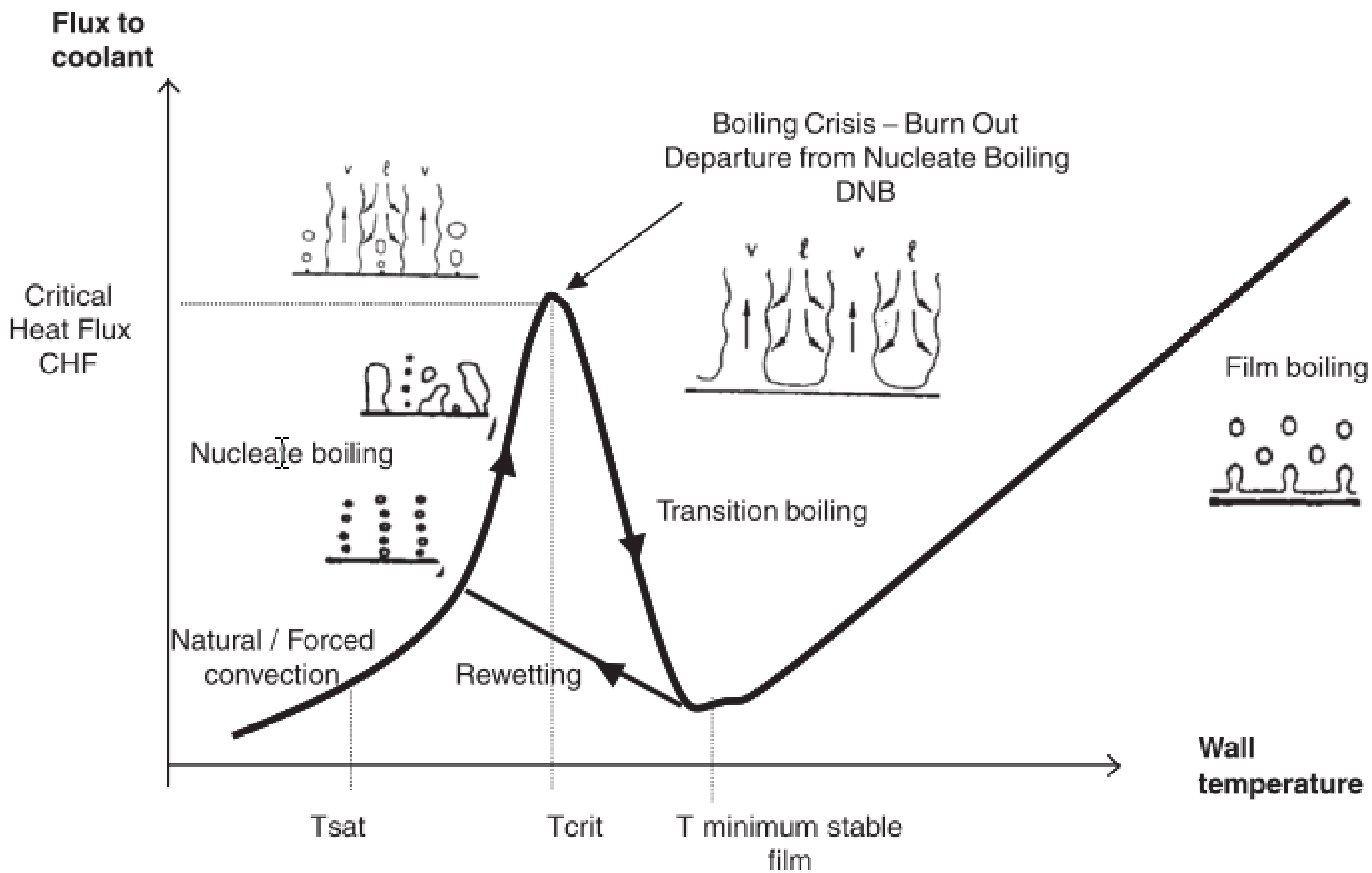
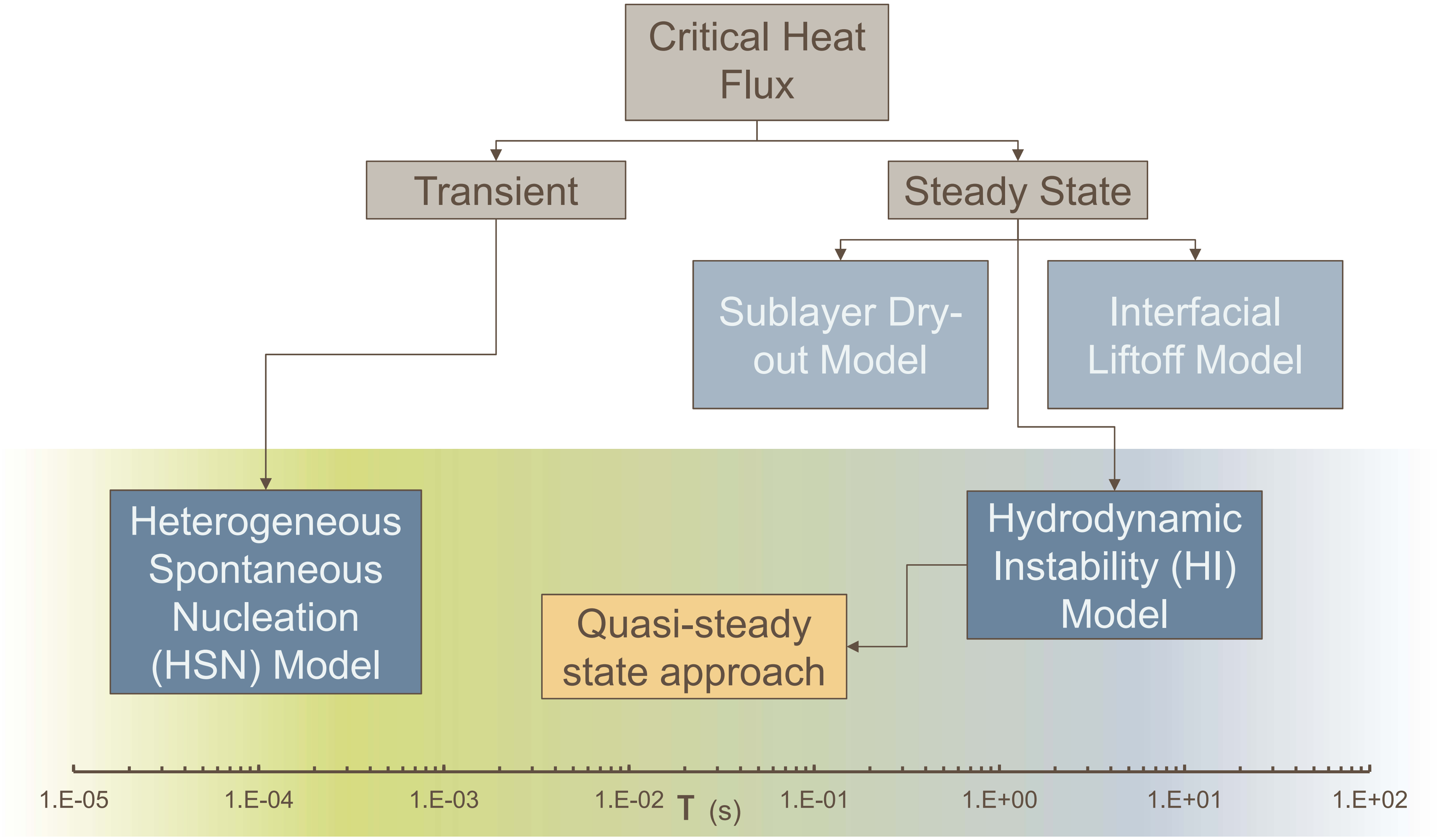


Fig. 8 Boiling Crisis mechanism in stationary and transient conditions [4]

Boiling Curve




Critical Heat Flux
Transient
Steady State
Sublayer Dry-out Model
Interfacial Liftoff Model
Heterogeneous Spontaneous Nucleation (HSN) Model
Hydrodynamic Instability (HI) Model
Quasi-steady state approach
1.E-05
1.E-04
1.E-03
1.E-02
T (s)
1.E-01
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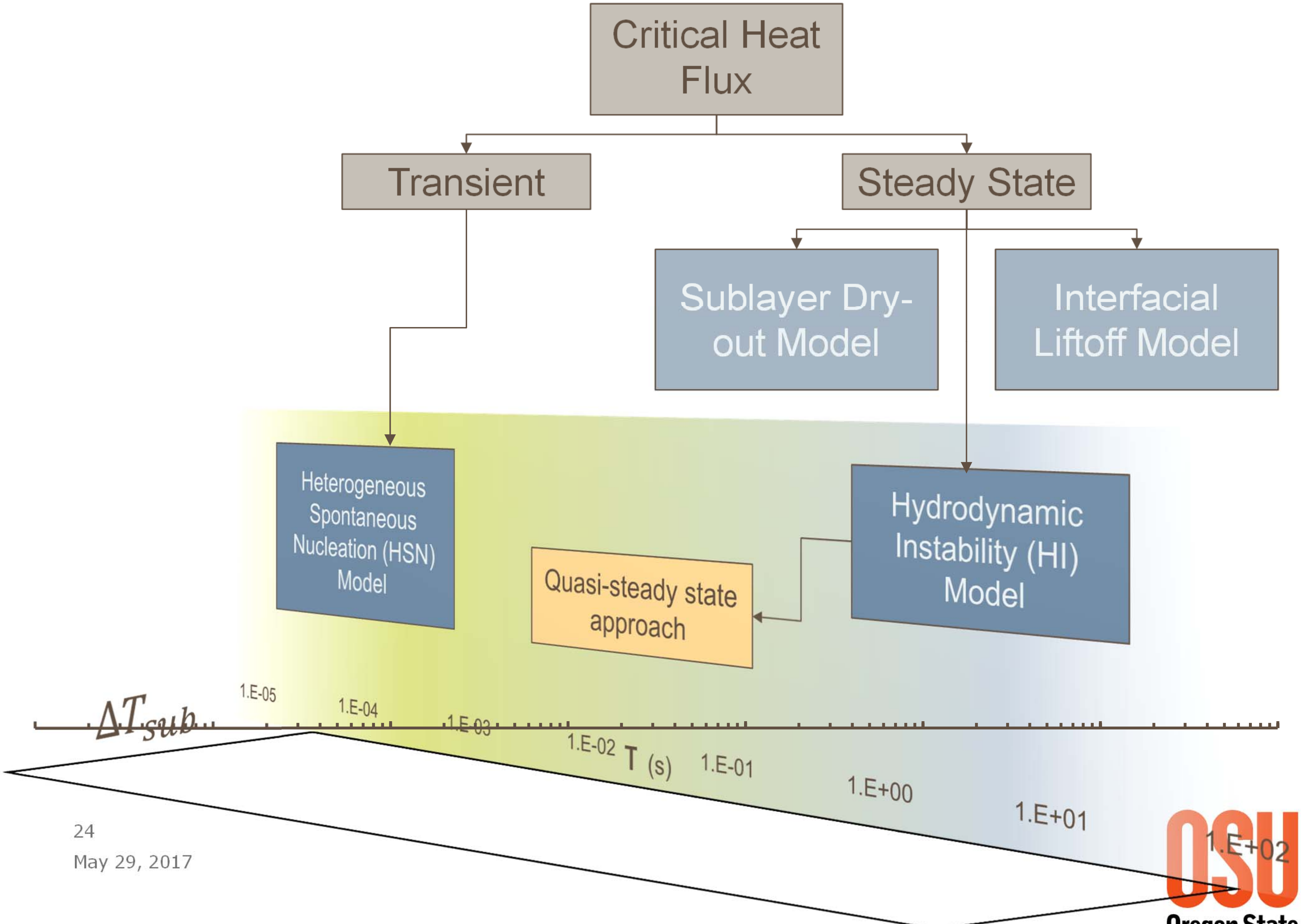
1.E+01
1.E+02


Critical Heat Flux
Transient
Steady State
Sublayer Dry-out Model
Interfacial Liftoff Model
Heterogeneous Spontaneous Nucleation (HSN) Model
Quasi-steady state approach
Hydrodynamic Instability (HI) Model
ΔT_{sub}
1.E-05
1.E-04
1.E-03
1.E-02
T (s)
1.E-01
1.E+00
1.E+01
1.E+02

Thank you for your time.

Questions?

References

[1] G. Bloch, M. Bruder, and T. Sattelmayer, “A study on the mechanisms triggering the departure from nucleate boiling in subcooled vertical flow boiling using a complementary experimental approach,” *Int. J. Heat Mass Transf.*, vol. 92, pp. 403–413, Jan. 2016.

[2] K. Pasamehmetoglu, “Transient Critical Heat Flux,” University of Central Florida, 1986.

[3] A. Sakurai, *Mechanisms of transitions to film boiling at CHFs in subcooled and pressurized liquids due to steady and increasing heat inputs*, vol. 197, no. 3. 2000.

[4] V. Bessiron, T. Sugiyama, and T. Fuketa, “Clad-to-Coolant Heat Transfer in NSRR Experiments,” *J. Nucl. Sci. Technol.*, vol. 44, no. 5, pp. 723–732, 2007.

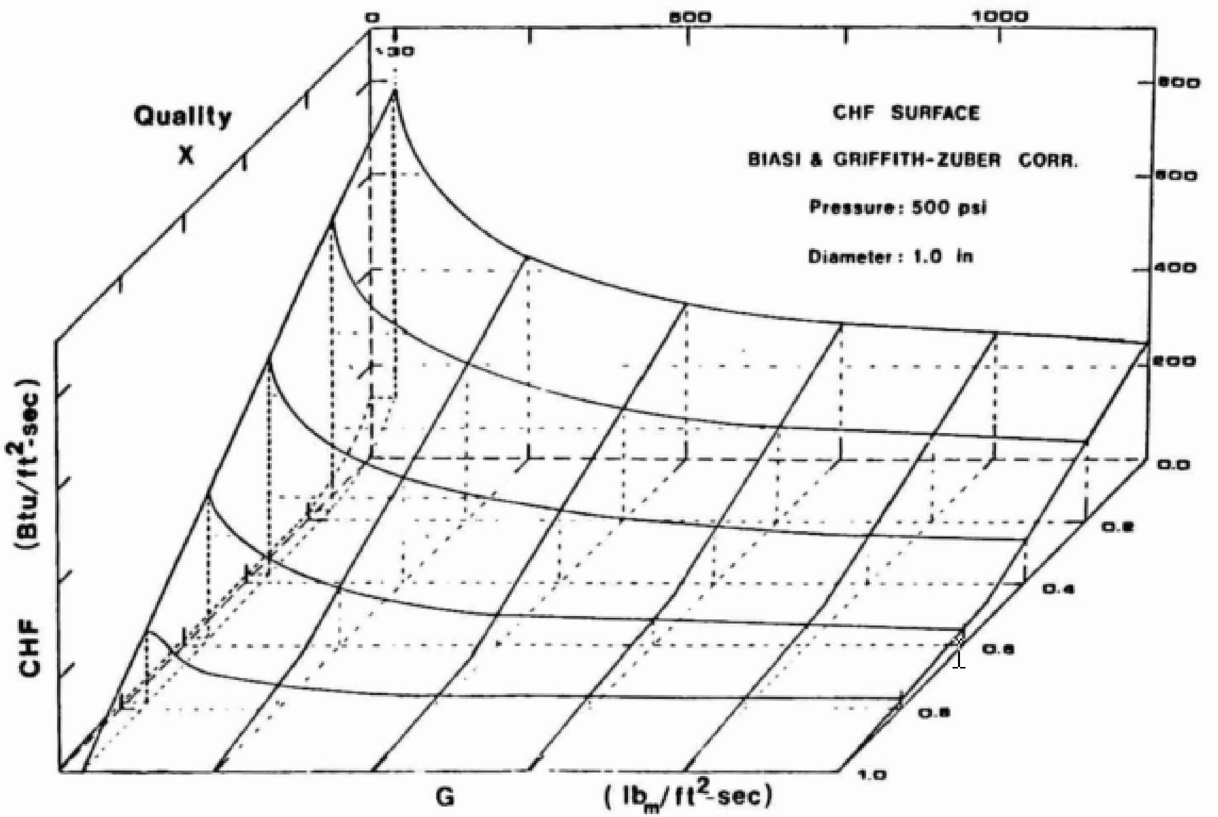
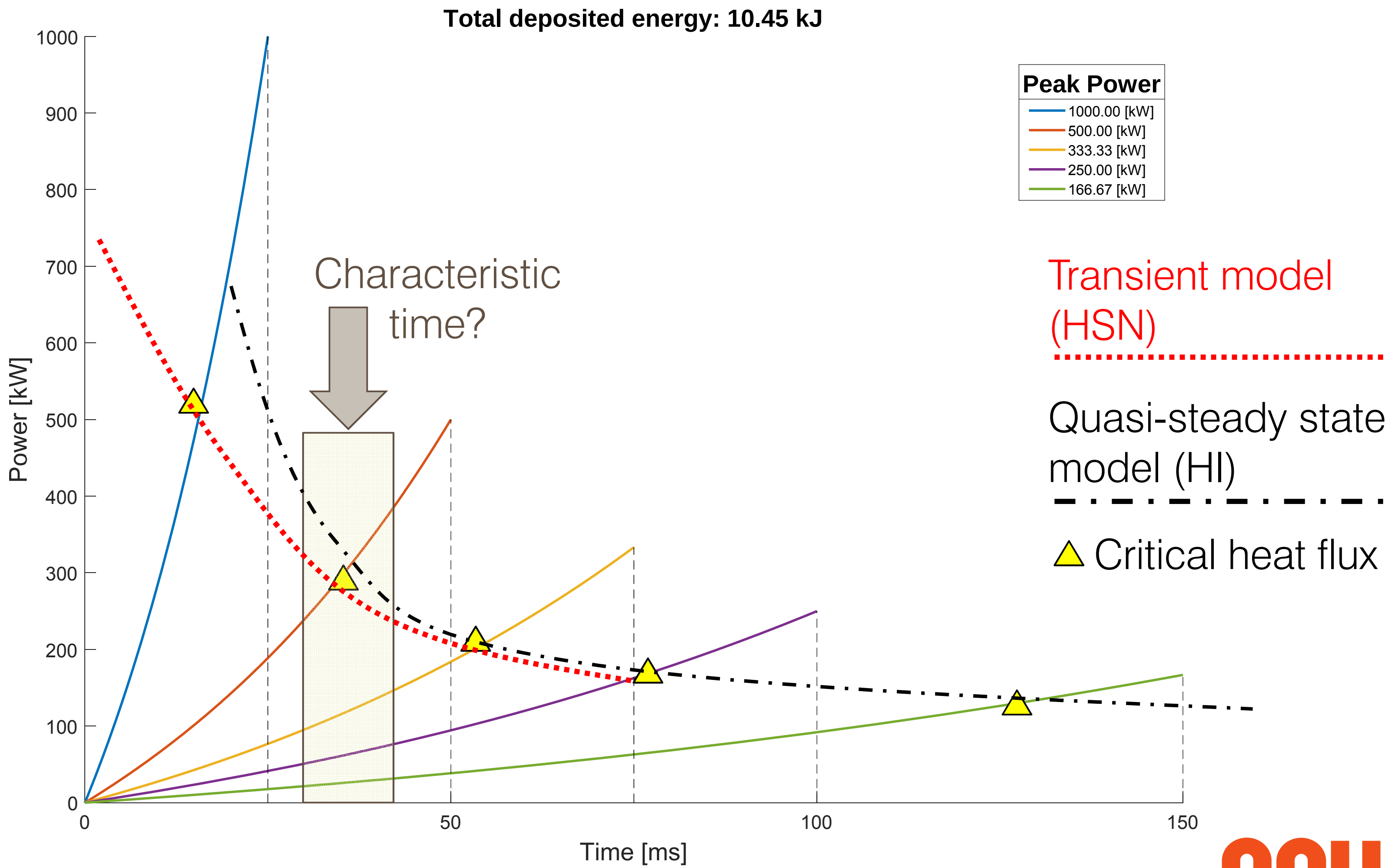


Figure 63. CHF Surface for 500 psi Pressure Generated from Biasi and Griffith-Zuber Correlations

tCHF Model Temporal Limitations

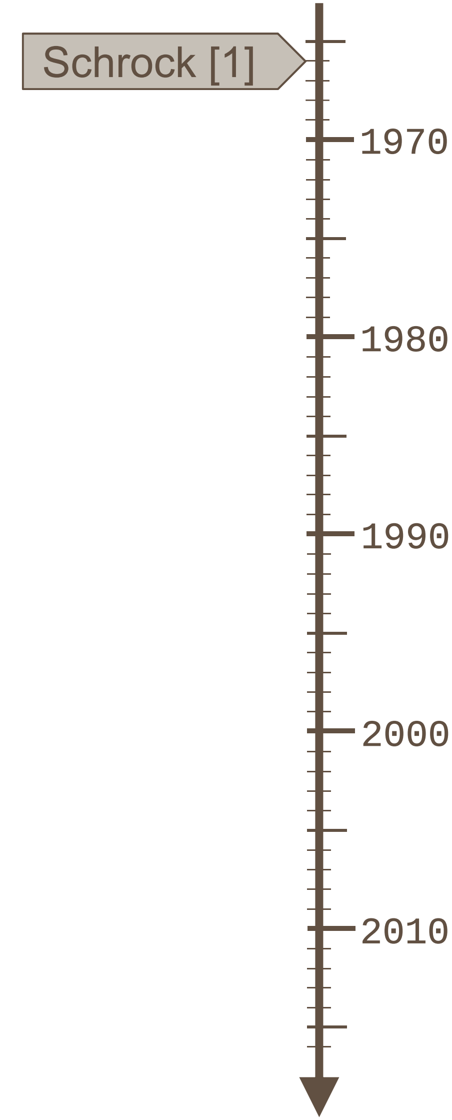


Literature Review

- Leidenfrost (1756) – First publication in boiling heat transfer.
- Nukiyama (1934) – Developed boiling curve.
- Zuber (1956) – Analytic saturated pool boiling CHF prediction.
- Kutateldze (1963-1966) – Suggests separation of hydrodynamic boundary layer is trigger mechanism for CHF.
- Schrock (1966) – Transient boiling phenomena.
- Tong (1966) – F-factor method (recommended as of Pasamehmetoglu).
- Tong (1968) – Agree with Kutateledze.
- Katto (1970) – Questions Zuber's model.
- Hsu (1976) – CHF dependent on upstream conditions or flow history. Implies integral method is required.
- Katto (1978:1980) – CHF correlations based on non-dimensional flow condition map (L, N, H, HP regimes).
- Katto (1979) – CHF in annuli.
- Leung (1980) – Transient Critical Heat Flux and Blowdown heat transfer studies
- Collier (1981) – Explored parameter dependence of CHF.
- Groenveld (1981) – Stated trends that correlations must follow.
- Katto & Haramura (1983) – Propose new hydrodynamic model "multi-step" model.
- Weisman & Pei (1983) – CHF associated with bubble boundary layer @ low quality, subcooled conditions.
- Dahlquist (1985) – CHF mapping suggested.
- Pasamehmetoglu (1986) – Transient Critical Heat Flux
- Celata (1989) - CHF behavior during pressure, power and/or flow rate simultaneous variations
- Sakurai (2000) - Mechanisms of transitions to film boiling at CHFs in subcooled and pressurized liquids due to steady and increasing (HSN Model)
- Bessiron (2007) – Modelling of Clad-to-Coolant Heat Transfer for RIA Applications Vincent

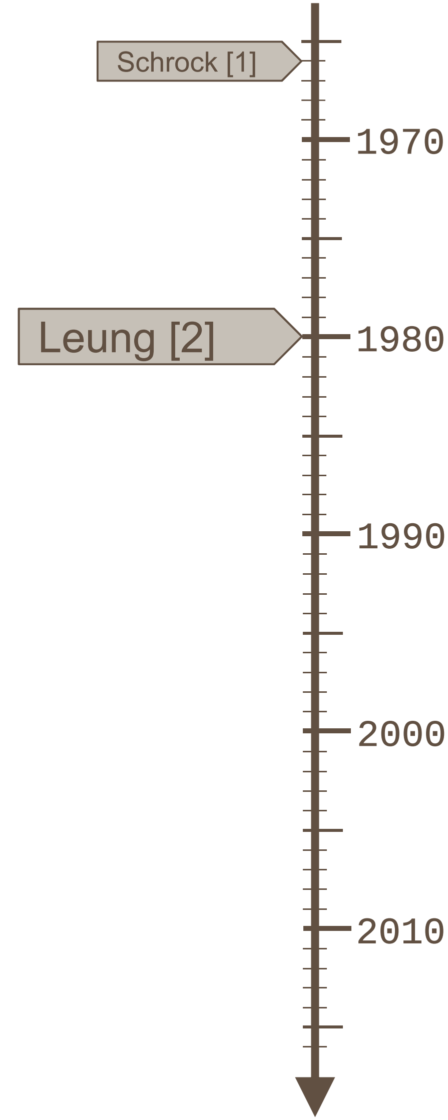
Schrock (1966)

Transient Boiling Phenomena



Leung (1980)

Transient Critical Heat Flux and Blowdown Heat-Transfer Studies



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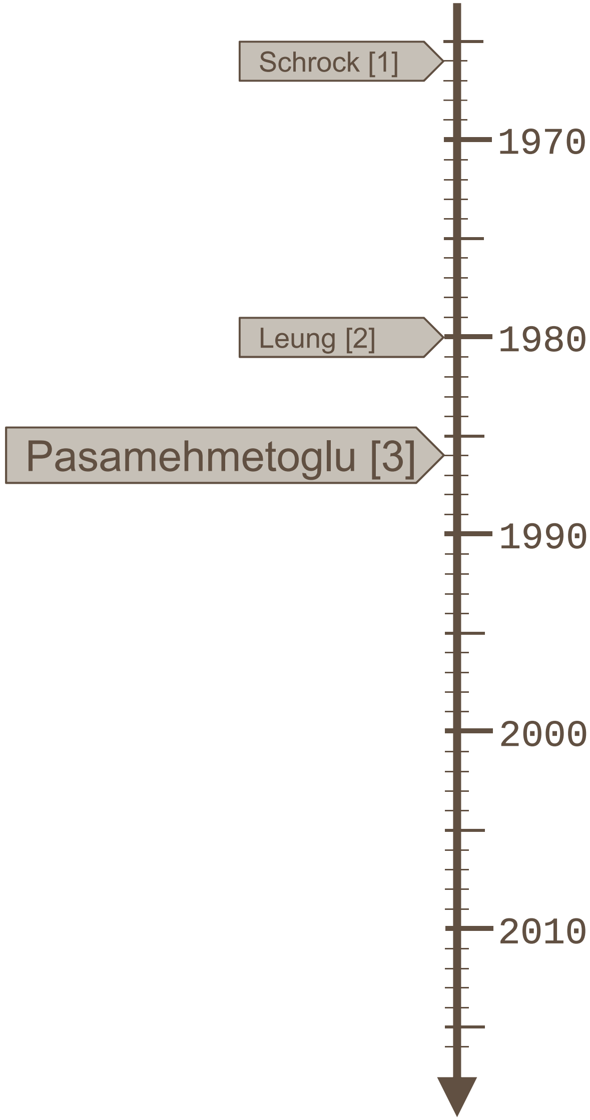
Pasamehmetoglu (1986)

Transient Critical Heat Flux



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Celata (1989)

CHF behavior during pressure, power and/or flow rate simultaneous variations