Light Water Reactor Sustainability Program

RELAP-7 Closure Verification
Part 1: Vertical Pre-CHF Closures

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Executive Summary

This report presents the efforts to verify the closure relations used in vertical pre-CHF flow regimes for RELAP-7. The RELAP-7 code is the next generation nuclear reactor system safety analysis code being jointly developed by the Idaho National Laboratory (INL) and Los Alamos National Laboratory(LANL). The overall design goal of RELAP-7 is to take advantage of the previous thirty years of advancements in computer architecture, software design, numerical integration methods, and physical models. The end result will be a reactor systems analysis capability that retains and improves upon RELAP5's and TRACE's capabilities and extends their analysis capabilities for all reactor system simulation scenarios.

The RELAP-7 code utilizes the well-posed 7-equation two-phase flow model for compressible two-phase flow. Closure models used in the TRACE code have been reviewed and selected to reflect the progress made during the past decades and provide a basis for the closure correlations implemented in the RELAP-7 code.

The vertical pre-CHF relations are in excellent agreement with the implementation in TRACE and are ready to be part of a more expanded developmental assessment effort.

Acknowledgements

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Introduction

The RELAP-7 (Reactor Excursion and Leak Analysis Program) code is the next generation nuclear reactor system safety analysis code being developed at Idaho National Laboratory(INL). The code is based on the INL's modern scientific software development framework MOOSE (Multi-Physics Object Oriented Simulation Environment) [1]. The overall design goal of RELAP-7 is to take advantage of the previous thirty years of advancements in computer architecture, software design, numerical integration methods, and physical models. The end result will be a reactor systems analysis capability that retains, and improves upon, RELAP5's [2] and TRACE's [3] abilities and extends the analysis capability for all reactor system simulation scenarios.

This document presents the verification activities on the closure relations used in vertical flow for pre-critical heat flux(CHF) flow conditions, that is, where the wall heat flux is less than that required for departure from nucleate boiling(DNB). Future reports will address verification of the closures for horizontal flow including stratified flow, as well as for Post-CHF conditions.

RELAP-7 Models

RELAP-7 can be perceived as having been derived from two major theoretical foundations, the first being a set of mathematical models to describe the physical phenomena being simulated, and the second being a set of numerical methods to act on those mathematical models to obtain meaningful outputs.

We assign these models into 4 categories:

- Basic equations models
- Flow-field and other constitutive models
- Component / equipment models
- Special-purpose models

Basic Equations Models

The basic equation models category includes the fundamental conservation and transport PDEs, as well as the thermodynamic state relations for the fluid (equation of state):

- Conservation of fluid mass
- Conservation of fluid momentum
- Conservation of fluid energy
- Heat Transfer
- Equation of state

Flow-Field and Other Constitutive Models

To model transfers of mass, momentum, and energy, both between fluid phases and between the fluid and wall, the basic equations must be supplemented with an additional set of models. These transfer models are derived from the literature and form the majority of the empirical correlations in RELAP-7.

Greater detail on the closure relations theory is presented in *RELAP-7 Closure Correlations* [4]

The flow-field and other constitutive models category includes the following:

- ❖ Flow regime maps
- ❖ Fluid mass exchange models
  - ➢ Wall mass transfer (boiling and condensation at the fluid-wall interface)

  - Interphase mass transfer (evaporation/flashing and condensation at the phasic interface)
- Fluid momentum exchange models
  - Wall momentum losses (drag)
  - Interphase momentum transfer (drag and entrainment)
  - Localized pressure losses (e.g., orifice plate, grid spacer, etc.)
- Fluid energy exchange
  - Wall energy transfer
  - Interphase energy transfer

Like TRACE, from which we derive most of our closures, RELAP-7 uses flow regime maps to determine which models to apply. Currently, RELAP-7 shares a map for interfacial drag and heat transfer, but has independent maps for wall drag and wall heat transfer.

Component / Equipment Models

RELAP-7, as a primarily 1D systems code, uses Component / Equipment models in situations where it is neither desirable, nor computationally feasible, to model components in full detail using only the fundamental basic equations models. Instead, component and equipment models use simplified input and output models to capture the relevant effects and performance of system components. Some subcategories of Component / Equipment models include the following:

- Centrifugal pump
- Check-valve
- Valve

Component / Equipment Models are verified as a part of the development of the component itself and are not verified here.

Verification Methodology

To check both the flow regime maps and the individual closure relations, we have chosen to verify specific points inside the domain of each correlation and every flow regime. We determine a set of thermal hydraulic properties and flow conditions, that use a particular correlation and verify that the flow regime logic selects the correct correlation and that the result matches what the TRACE code implementation provides.

To verify these states, we have developed a capability in RELAP-7 to calculate the output of these relations without running a full model. This ensures that we can precisely set the flow conditions even in states that are far from equilibrium.

We have also created a similar standalone utility based on the TRACE Modules for closure relations provided by the US Nuclear Regulatory Commission. This utility receives a complete set of flow conditions and thermodynamic state, and with these values computes the correlated value. For the TRACE property utility, we have bypassed TRACE's Equation of State (EOS) package and provide all required thermodynamic properties to these utilities based on the RELAP-7 formulation of IAPWS-95. This avoids issues in variations due to the evaluation of thermodynamic properties, and simplifies the utility logic as it does not need to instantiate TRACE components.

These capabilities assure that we will be able to continually verify that the closure relations are properly implemented with greater confidence than can be obtained simply through the use of validation test cases.

Choice of Verification Conditions

For Part 1, vertical correlations less that the critical heat flux or DNB, a matrix of 36 cases was developed for wall drag, interfacial drag, interfacial heat transfer, and wall heat transfer. The cases were selected with the intent to test each combination of fluid state (subcooled, saturated, superheated, void fraction, and flow regime) that results in a different closure being utilized according to the coded logic in RELAP-7. For wall drag, interfacial drag, and interfacial heat transfer closures, the two-phase flow regimes include bubbly/slug, annular/mist, cap bubble/slug, and transition regions. For wall heat transfer only the pre-DNB closures were tested, and these included laminar and turbulent forced convection, laminar and turbulent natural convection, film condensation, and transition regions.

For wall drag seven cases were tested. For interfacial drag six cases were tested. For interfacial heat transfer five cases were tested. For wall heat transfer eighteen cases were tested. The figure below shows the coded logic in RELAP-7 for wall heat transfer, with each branch of the logic tree considered in the selection of test cases.

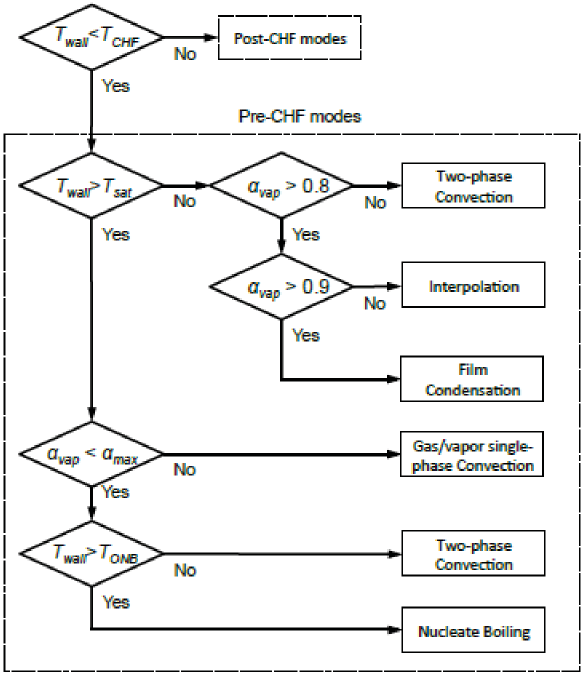

Figure 4. Logic to determine pre-CHF wall heat transfer mode following TRACE code [3].

Three types of test problems were used in the 36 test cases. For the wall drag and interfacial drag cases, measured data and small extensions of the measured data were used to test the RELAP-7 closures. The wall drag test data used were the Ferrell-McGee data that were used for the TRACE code validation. The interfacial drag test data used were the Argonne air-water test data, also used for the TRACE code validation. For the interfacial heat transfer cases a dummy RELAP-7 Pipe component test problem consisting of a 0.1 meter diameter pipe at ~500°K was created. For the wall heat transfer test cases three test problems were used. The first was the same dummy Pipe component test problem. The second was a single fuel rod and subchannel RELAP-7 RodBundle component based on the BEAVRS PWR neutronics benchmark database, which is applicable to a Westinghouse 17x17 fuel assembly design with a 0.360 inch diameter fuel rod. The third was the Christensen Test 15 data used for the turbulent forced convection test case.

For many of the 36 test cases the RELAP-7 input file parameter values required some adjustments so that the RELAP-7 coded logic would result in testing the desired closure. Parameter values that were candidates for adjustment were the power, the fluid velocity, and the hydraulic diameter.

Verification Results

RELAP-7 and TRACE provide nearly identical values for each of the conditions evaluated, in all cases yielding less than 1% difference between codes. We believe that these differences are primarily due to a lack of precision in input thermodynamic state, and to a lesser extent, differences in compiler optimization and order of operations. Because of this, unless stated otherwise, results presented in the following tables match both RELAP-7 and TRACE to the precision presented in the table. All values are in SI units.

In the course of verifying these relations, we have come across both implementation errors in RELAP-7 and errors in documentation of TRACE. For the vertical flow relations, all of these issues have been resolved. We know of no errors with respect to the relations in TRACE or RELAP-7 at this time.

Wall Drag

Table 1: Wall Drag verification cases

Wall Drag			**T/H Conditions**	**Reference (INL/EXT-17-41653)**
Single-Phase		Liquid	**1) Ferrell-McGee Subcooled Data** TRACE App. A, p. A-62; T = 384.01 (70 K subcooled) P = 1.023e6 Pa D_h = 0.0508 m A = 2.027e-3 m2 Vel_liquid = 5.45e-02 m/s **RESULTS** **Cw_liquid = 7.664E-3** **Cw_vapor = 0**	Eqn 10, p. 13
Single-Phase		Vapor	2) **Ferrell-McGee Superheated Data** TRACE App. A, p. A-62; T = 484.01 K (30 K superheated) P = 1.023e6 Pa D = 0.0508 m A = 2.027e-3 m2 Vel_vapor = 7.07e-01 m/s **RESULTS** **Cw_liquid = 0** **Cw_vapor = 7.625E-3**	Eqn 10, p. 13

Two-Phase	Bubbly/Slug	Liquid with subcooled boiling	3**) Dummy Problem** T_liquid = 500 K T_vapor = 520 K T_wall = 500 K P = 3.768e6 Pa (Psat for 520 K) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 1.0 m/s Vel_vapor (air) = 1.0 m/s Alpha_vapor = 0.1 **RESULTS** **Cw_liquid = 3.082E-3** **Cw_vapor = 0**	Eqn 18, p. 14
Two-Phase	Bubbly/Slug	Liquid with nucleate boiling	4) **Ferrell-McGee Saturated Data** TRACE App. A, p. A-71, Test 1A-8 P = 8.184e5 Pa T_liquid = 444.50 K (Tsat) T_vapor = 444.50 K (Tsat) T_wall = 445 K Alpha_vapor = 0.536 Mass flow = 0.0582 kg/s D = 0.01168 m A = 1.071e-4 m2 Vel = 1.299 m/s **RESULTS** **Cw_liquid = 1.884E-2** **Cw_vapor = 0**	Eqn 20, p. 15

Two-Phase	Transition	0.8 < α< 0.9	5) **Ferrell-McGee Saturated Data** TRACE App. A, p. A-71, Test 1A-2 P = 8.211e5 Pa T = 444.63 K (Tsat) Alpha_vapor = 0.825 Mass flow = 0.0581 kg/s D = 0.01168 m A = 1.071e-4 m2 Vel = 3.393 m/s **RESULTS** **Cw_liquid = 4.216E-3** **Cw_vapor = 0**	Eqn 32, p. 16
Two-Phase	Annular/Mist	Full liquid film (>25 microns)	6**) Ferrell-McGee Saturated Data** TRACE App. A, p, A-71, Test 1A-6 P = 8.246e5 Pa T = 444.81 K (Tsat) Alpha_vapor = 0.981 Mass flow = 0.0580 kg/s D = 0.01168 m A = 1.071e-4 m2 Vel = 25.52 m/s **RESULTS** **Cw_liquid = 3.734E-3** **Cw_vapor = 0**	Eqn 24, p. 15

Two-Phase	Annular/Mist	Partial liquid film (<25 microns based on α and wetted perimeter)	7**) Dummy Problem (extending #6 with higher void fraction)** P = 8.246e5 Pa T = 444.81 K (Tsat) Alpha_vapor = 0.992 (0.99143 = 25 micron) Mass flow = 0.0580 kg/s D = 0.01168 m A = 1.071e-4 m2 Vel = 25.52 m/s **RESULTS** **Cw_liquid = 3.371E-3** **Cw_vapor = 1.263E-3**	Eqn 28, p. 16

Interfacial Drag

Table 2. Interfacial Drag verification cases.

Interfacial Drag				
	Bubbly/Slug	Pipe bubbly (α <0.2)	8) **ANL Air-Water Test B-14** TRACE App. A, p. A-33, ANL-6755 T = 293.15 K P = 1.013e5 Pa D_h = 0.06985 (2.75 inch ID) A = 0.04124 m2 Vel_liquid = 0.030 m/s Vel_vapor (air) = 0.048 m/s Alpha_vapor = 0.108 **RESULTS** **F_int = 1.403E+4**	Eqn 65, p. 23 Eqn 67, 68. p. 24
	Bubbly/Slug	Transition ($0.2 < \alpha < 0.3$)	9) **ANL Air-Water Test B-13** TRACE App. A, p. A-33, ANL-6755 T = 293.15 K P = 1.013e5 Pa D_h = 0.06985 (2.75 inch ID) A = 0.04124 m2 Vel_liquid = 0.030 m/s Vel_vapor (air) = 0.217 m/s Alpha_vapor = 0.299 (note that test was actually 0.303) **RESULTS** **F_int = 7.094E+3**	Eqn 73, p. 25

	Bubbly/Slug	Pipe cap/slug (0.3 < α < ~0.90)	10) **ANL Air Water Test H-2** TRACE App. A, p. A-33, ANL-6755 T = 293.15 K P = 1.013e5 Pa D_h = 0.06985 (2.75 inch ID) A = 0.04124 m2 Vel_liquid = 0.305 m/s Vel_vapor (air) = 2.874 m/s Alpha_vapor = 0.652 **RESULTS** **F_int = 1.878E+3**	Eqn 65, p. 23 Eqn 68, 69, p. 24
	Bubbly/Slug	Rod Bundle	11) **ANL Air-Water Test B-14** TRACE App. A, p. A-33, ANL-6755 T = 293.15 K P = 1.013e5 Pa D_h = 1.295E-4 m (BEAVRS rod bundle) P/D = 1.37 A = 9.303e-5 m2 Vel_liquid = 0.030 m/s Vel_vapor (air) = 0.048 m/s Alpha_vapor = 0.108 **RESULTS** **F_int = 2.016E+4**	Eqn 65, p. 23 Eqn 77, p. 25
	Mixing	α ≈0.90	12) **Dummy Problem (extending ANL Test G-17 - highest void test)** T = 293.15 K P = 1.013e5 Pa D_h = 0.06985 m (2.75 inch ID)	Eqn 100, p. 29

			A = 0.04124 m2 Vel_liquid = 0.244 m/s Vel_vapor (air) = 3.762 m/s Alpha_vapor = 0.849 **RESULTS** **RELAP-7: F_int = 199.9** **TRACE: F_int =200.6**	
	Annular/Mist	α > ~0.90	13) **Dummy Problem (extending ANL Test G-17 - highest void test)** T_vapor = 293.15 K T_wall = 293.15 K T_liquid = 493.15 K P = 1.013e5 Pa D_h = 0.06985 m (2.75 inch ID) A = 0.04124 m2 Vel_liquid = 0.01 m/s Vel_vapor (air) = 1.0 m/s Alpha_vapor = 0.85 **RESULTS** **F_int = 196.08**	Eqn 78, p. 26

Interfacial Heat Transfer

Table 3. Interfacial Heat Transfer verification cases.

Interfacial Heat Transfer				
	Bubbly Flow		**14) Dummy Pipe Problem** T_liquid = 500 K T_vapor = 520 K P = 2.639e6 Pa (Psat for 500 K) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 2.0 m/s Vel_vapor = 2.0 m/s Alpha_vapor = 0.1 **RESULTS** **Vhtc_liquid = 4.87e4** **Vhtc_vapor = 1.51e5**	Eqn 143, p. 38 Eqn 149, p. 38
	Cap Bubble/Slug Flow		**15) Dummy Pipe Problem** T_wall = 500 T_liquid = 500 K T_vapor = 520 K P = 2.639e6 Pa (Psat for 500 K) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 3.0 m/s Vel_vapor = 3.0 m/s Alpha_vapor = 0.3 **RESULTS** **Vhtc_liquid = 1.46e5** **Vhtc_vapor = 4.54e5**	Eqn 155, p. 39 Eqn 161, p. 40

	Transition	0.5 < α< 0.75	**16) Dummy Pipe Problem** T_wall = 500 T_liquid = 500 K T_vapor = 520 K P = 2.639e6 Pa (Psat for 500 K) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 5.0 m/s Vel_vapor = 5.0 m/s Alpha_vapor = 0.6 **RESULTS** **Vhtc_liquid = 9.80e5** **Vhtc_vapor =2.00e5**	Eqn 191, p. 44
	Correction for Subcooled Boiling for Dispersed Bubbles		**17) Dummy Pipe Problem** T_wall = 500 K T_liquid = 480 K T_vapor = 520 K P = 2.639e6 Pa (Psat for 500 K) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 2.0 m/s Vel_vapor = 2.0 m/s Alpha_vapor = 0.1 **RESULTS** **Vhtc_liquid = 1.71e5** **Vhtc_vapor =1.43e5**	Eqn 166, p. 41

	Annular/Mist Flow		18) **Dummy Pipe Problem** T_wall = 500 T_liquid = 500 K T_vapor = 520 K P = 2.639e6 Pa (Psat for 500 K) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 15.0 m/s Vel_vapor (air) = 15.0 m/s Alpha_vapor = 0.9 **RESULTS** **Vhtc_liquid = 1.05e7** **Vhtc_vapor =1.83e5**	Eqn 167, p. 41

Wall Heat Transfer

Table 4. Wall heat transfer verification cases.

Wall Heat Transfer				
Single-Phase Liquid	Pipe	α = 0	19) **Laminar Forced Convection** Dummy Pipe Problem T_liquid = 500 K (Psat = 2.639e6) P = 5.0e6 Pa (>Psat) T_wall = 500 K D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 1.0e-3m/s **RESULTS** **Hw = 27.8**	Eqn 226, p. 52
			20) **Turbulent Forced Convection** **Christensen Test 15,** INL/EXT-98-0083, Vol. 3, p. 4-47; ANL-6385 (p. 96) T = 530.84 K (12.5 K subcooling) T_wall = 550 K P = 5.52e6 MPa D_h = 0.0176 m A = 4.928e-4 m2 Vel = 1.15 m/s Q_wall = 9.93e5 W/m2 (70 kW) P_hf = 0.111 m (1.11 cm x 4.44 cm square duct; 1.27 m height) A = 4.9284e-4 m2 **RESULTS**	Eqn 230, p. 52

			Hw = 9738	
			21) **Laminar Natural Convection** **Dummy Pipe Problem** T_liquid = 500 K P = 5.0e6 Pa (>Psat) T_wall = 500 K D_h = 0.02 m A = 7.85e-3 m2 Vel_liquid = 1.0e-3 **RESULTS** **Hw = 1610**	Eqn 232, p. 53
			22) **Turbulent Natural Convection** **Dummy Pipe Problem** T_liquid = 500 K P = 5.0e6 Pa (>Psat) T_wall = 510 K D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 1.0e-2 **RESULTS** **Hw = 1562**	Eqn 233, p. 53
Single-Phase Liquid	Rod Bundle	α = 0	23) **Laminar Forced Convection** **BEAVRS Rod Bundle** T_liquid = 500 K P = 5.0e6 Pa (>Psat) T_wall = 510 K D_h = 1.295E-4 m PoD = 1.37 A = 9.303e-5 m2 Vel_liquid = 1.0 m/s	Eqn 237, p. 53

			RESULTS **Hw = 6.33e4**	
			24) **Turbulent Forced Convection** **BEAVRS Rod Bundle** T_liquid = 500 K P = 5.0e6 Pa T_wall = 510 K D_h = 1.295E-4 m PoD = 1.37 A = 9.303e-5 m2 Vel_liquid = 6 m/s **RESULTS** **Hw = 1.48e5**	Eqn 243, p. 54
			25**) Natural Convection** **BEAVRS Rod Bundle** T_liquid = 500 K P = 5.0e6 Pa T_wall = 510 K P/D = 1.37 D_h = 1.295E-2 m (BEAVRS divided by 100) A = 9.303e-5 m2 Vel_liquid = 0.01 m/s **RESULTS** **Hw = 2130**	Eqn 244, p. 54
Two-Phase	Pipe	0 < α < 0.8 Tw > Tsat Tw < Tonb	26) **Laminar Forced Convection** **Dummy Pipe Problem** T = 520 K (Tsat) P = 3.768e6 Pa (Psat) Q_wall = 1.0e-5 W/m2 T_wall = not specified T_liquid = 520 K	Section 6.1.2, p. 54 describes the modified liquid phase Reynolds number that is applied to the single phase closures

			T_vapor = 520 K D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 1.0e-3 Vel_vapor = 1.0e-3 Alpha_vapor = 0.1 **RESULTS** **Hw_liquid = 26.90** **Hw_vapor =0**	
			27**) Turbulent Forced Convection** **Dummy Pipe Problem** T = 520 K (Tsat) P = 3.768e6 Pa (Psat) Q_wall = 1.0e-5 W/m2 T_wall not specified T_liquid = 520 K T_vapor = 520 K D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 4 m/s Vel_vapor = 4 m/s Alpha_vapor = 0.1 **RESULTS** **Hw_liquid = 1.98e4** **Hw_vapor = 0**	

			28) **Laminar Natural Convection** **Dummy Pipe Problem** T = 520 K (Tsat) P = 3.768e6 Pa (Psat) Q_wall = 1.0e-5 W/m2 T_wall not specified T_liquid = 520 K T_vapor = 520 K D_h = 0.2 m A = 7.85e-3 m2 Vel_liquid = 0.5e-3 m/s Vel_vapor = 0.5e-3 m/s Alpha_vapor = 0.01 **RESULTS** **Hw_liquid = 15.5** **Hw_vapor = 0**	
Two-Phase	Rod Bundle	$0 < \alpha < 0.8$ Tw > Tsat Tw < Tonb	29) **Laminar Forced Convection** **BEAVRS Rod Bundle** T = 520 K (Tsat) P = 3.768e6 Pa (Psat) T_wall = not specified Q_wall = 1.0e-5 W/m2 T_liquid = 520 K T_vapor = 520 K D_h = 1.295E-4 m	Section 6.1.2, p. 54 describes the modified liquid phase Reynolds number that is applied to the single phase closures

			PoD = 1.37 A = 9.303e-5 m2 Vel_liquid = 1.0e-3 m/s (from above) Vel_vapor = 1.0e-3 m/s Alpha_vapor = 0.4 **RESULTS** **Hw_liquid = 3.55e4** **Hw_vapor = 0**	
			30) **Turbulent Forced Convection** **BEAVRS Rod Bundle** T = 520 K (Tsat) P = 3.768e6 Pa (Psat) T_wall = not specified Q_wall = 1.0e-5 W/m2 T_liquid = 520 K T_vapor = 520 K D_h = 1.295E-4 m Vel_liquid = 6 m/s Vel_vapor = 6 m/s Alpha_vapor = 0.4 **RESULTS** **Hw_liquid = 1.49e5** **Hw_vapor = 0**	
			31) **Laminar Natural Convection** **BEAVRS Rod Bundle** T = 520 K (Tsat) P = 3.768e6 Pa (Psat) T_wall = not specified Q_wall = 1.0e-5 W/m2 T_liquid = 520 K	

			T_vapor = 520 K D_h = 1.295 m (BEAVRS divided by 1.0e4) PoD = 1.37 Vel_liquid = 1.0e-5 m/s Vel_vapor = 1.0e-5 m/s Alpha_vapor = 0.4 **RESULTS** **Hw_liquid = 16.0** **Hw_vapor = 0**	
	Film Condensation	Tw < Tsat 0 .9 < α < 0.9999	32) **Turbulent** **Dummy Pipe Problem** T_liquid = 520 K (Tsat) T_wall = 500 K Q_wall not specified T_vapor = 520 K P = 3.768e6 Pa (Psat) D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 6.0 m/s Vel_vapor = 6.0 m/s Alpha_vapor = 0.95 **RESULTS** **Hw_liquid = 6.19e4** **Hw_vapor = 0**	Eqn 251, p. 55

	Transition from forced convection to film condensation	Tw ≤ Tsat 0.8 < α < 0.9	33) **Turbulent Forced Convection** **Dummy Pipe Problem** T = 523.5 K (Tsat) P = 4.0e6 Pa Q_wall = 6.375 W/m2jh T_wall not specified T_liquid = 520 K T_vapor = 520 K D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 4 m/s Vel_vapor = 4 m/s Re = 2.98e5 Alpha_vapor = 0.85 **RESULTS** **Hw_liquid = 2.85e4** **Hw_vapor = 0**	Section 6.1.4 (p. 55) describes the interpolation used between two-phase and condensation
	Pipe Wall Boiling	Subcooled Nucleate Boiling Tl iq < Tsat Tw < Tonb α > 0	34) **Subcooled Liquid** **Dummy Pipe Problem** T = 510 K (Tsat = 520 K) T_wall = 520 K Q_wall not specified T_liquid = 510 K T_vapor = 510 K P = 3.768e6 Pa (Psat)	Section 6.1.5 (p. 56) describes the development

			D_h = 0.1 m A = 7.85e-3 m2 Vel_liquid = 4 m/s Vel_vapor = 4 m/s Alpha_vapor = 0.1 **RESULTS** **Hw_liquid = 1.98e4** **Hw_vapor = 0**	
	Pipe Wall Boiling	Nucleate Boiling Tliq = Tsat Tw > Tonb α > 0	35) **Saturated Liquid Dummy Pipe Problem** T = 520 K (Tsat) T_wall =534 K Q_wall not specified T_liquid = 520 K T_vapor = 520 K P = 3.768e6 Pa (Psat) D_h = 0.1 m A = 7.85e-3 m2 Rho_l = 803.5kg/m3 Rho_g =18.894kg/m3 µ_l = 1.077e-4 Pa-s µ_g = 1.731e-5 Pa-s Vel_liquid = 4 m/s Vel_vapor = 4m/s Re = 2.98e6 α = 0.1 **RESULTS** **Hw_liquid = 1.87e5** **Hw_vapor = 0**	Section 6.1.5 (p. 56) describes the development

Conclusions

Based on the excellent agreement between TRACE and RELAP-7, we feel confident that the TRACE closure correlations for vertical pre-CHF flow conditions have been implemented correctly. Once the remaining correlations have been verified and coupled with appropriate components models, RELAP-7 will be ready for an expanded developmental assessment where the interaction of the closure relations, solution algorithms, and component models can be demonstrated, evaluated and assessed.

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