Development of a Quality-Assured HTTF RELAP5-3D Input Model

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Overview

- High Temperature Test Facility (HTTF) description
- RELAP5-3D input model description
- Input model development
- Quality assurance review
- Summary and conclusions

HTTF Description

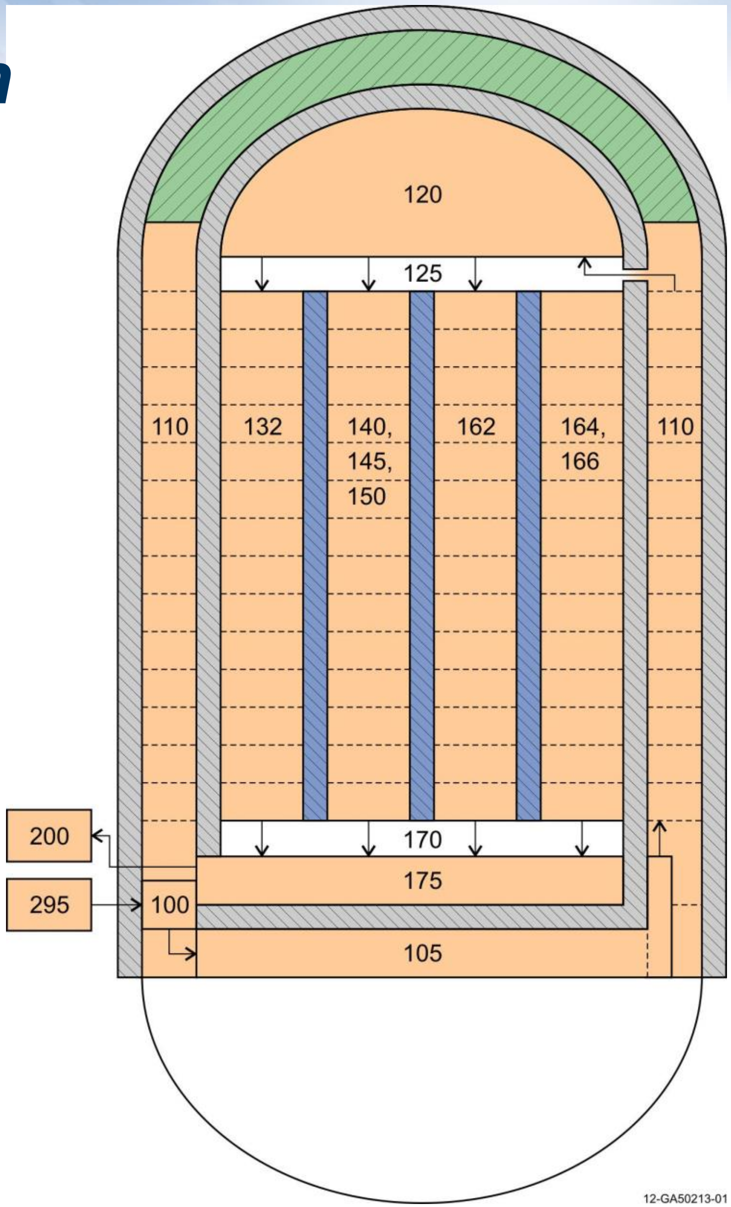
- Integral experiment being built at Oregon State University
- 2.2 MW electrically-heated, scaled model of a high temperature gas reactor
  - Reference is the Modular High-Temperature Gas-cooled Reactor (MHTGR) (prismatic blocks)
  - Large ceramic block representing core and reflectors
  - ¼ length scale
  - Prototypic coolant inlet (259°C) and outlet (687°C) temperatures
  - Maximum pressure of ~700 kPa
- Three cooling systems
  - Primary
  - Secondary (steam generator)
  - Reactor cavity

HTTF RELAP5-3D Input Model Description

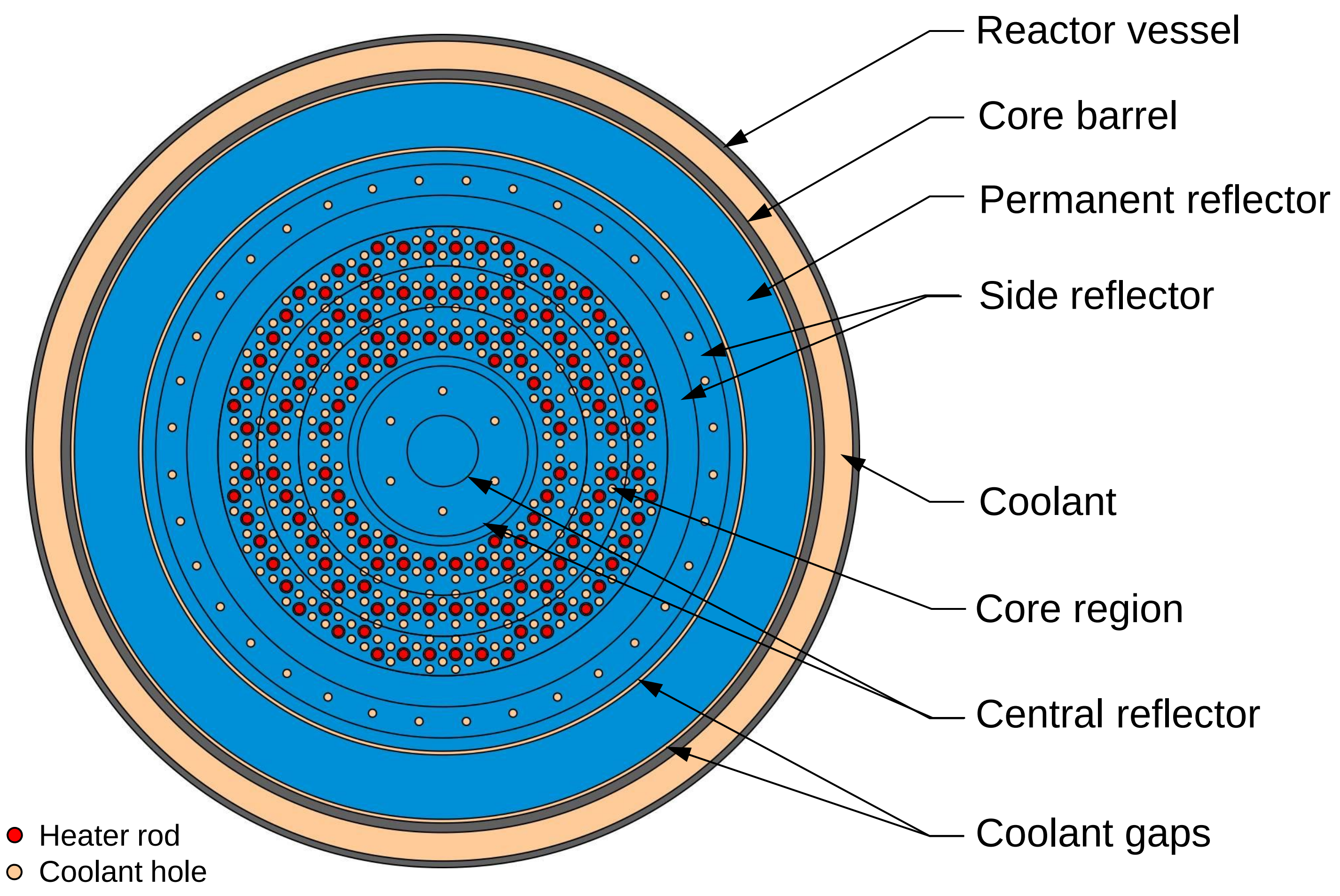
- Four systems
  - Primary coolant
  - Secondary coolant
  - Reactor cavity
  - Reactor cavity cooling system (RCCS)
- Central and side reflector regions divided into regions with or without coolant holes
- 2-D (radial/axial) conduction in all vertical heat structures
- Heater block unit cell centered on the coolant channel
- Radial conduction and radiation inside core barrel
- Radiation from core barrel to vessel to RCCS

Reactor Vessel Nodalization

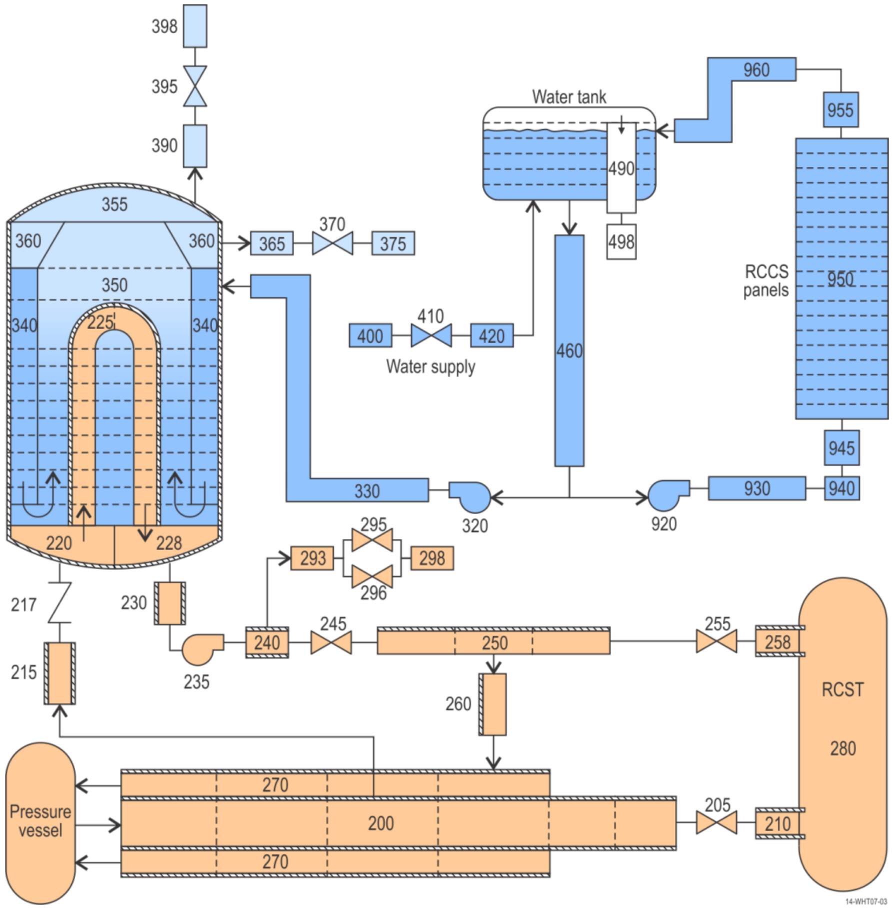
- Multiple flow paths through core
  - Three heated channels
  - Central reflector
  - Side reflector
- Gaps on either side of permanent side reflector not flow-through
- Riser annulus between core barrel and pressure vessel
- No coolant between upper plenum shield and upper head



HTTF RELAP5-3D Core Region Radial Nodalization



HTTF Ex-vessel Nodalization



Traditional Model Development Approach

- Hand calculations on paper
  - Eventually moved to Word-based documents with the same information
- Advantages
  - Easy to see calculations
  - Straightforward to check
  - Everything in one (large) document
- Disadvantages
  - Very difficult to change (especially to propagate changes throughout the model)
  - Higher potential for math errors
  - More potential for errors in transcribing input to electronic file
  - Hard to share

Current Approach

- Excel workbook
- Advantages
  - Compact input
  - Less prone to math errors
  - Easily changed (important for evolving designs or sensitivity analysis)
  - Fewer transcription errors
  - Easy to share
  - Track changes feature allows interim quality assurance reviews and verification of corrections/changes (but it needs to be set up at the beginning)
- Disadvantages
  - More difficult initial setup
  - Harder to check
  - Need a companion model description document

Model Description Document

- Helps reviewer understand what you're doing
- Becomes the model notebook
- Excerpt:

> Structure 1150 is the core barrel. It has 16 axial structures (cell 1 is at the bottom), is made of 304 stainless steel [dwg. 25835-1, sh. 1, Rev. AB, item 86], and is connected to Components 166 and 175 on the left side and Components 110 and 115 on the right side. Axial conduction is turned on. The left side of the structure is in a radiation enclosure with the PSR, and the right side is in a radiation enclosure with the primary pressure vessel barrel and the jacket shell.

HTTF Workbook Spreadsheets

- Comments
- Geometry
- RELAP5 input
- Materials
- Convars
- Power
- References
- Benchmarking
- Test 140
- Test 150

Geometry Spreadsheet Excerpt

Valve V-311	
0.02946029	flow area (m2)
0.2027174	hydraulic diameter
5	valve stroke time (s)
2.20E+05	approximate cold leg Re {(mass flow / A) x D / μ}
0.017	f_T for 8" pipe [Crane, pg. 3-19]
0.136	K for gate valve (K = 8 f_T) [Crane, pg. A-27]
0	reverse loss coefficient
Pipe from valve V-311 into RCST	
8	nominal pipe size (in.) [Dwg. 25836, sh. 1, Rev. AB, item N11]
80	pipe schedule [Dwg. 25836, sh. 1, Rev. AB, item N11]
8.625	outer diameter (in.) [Crane, pg. B-17]
7.625	inner diameter (in.) [Crane, pg. B-17]
2	insulation thickness (in.) [e-mail from M. Hertel to B. Woods, *Insulation Info for HTTF*, 12/12/2014]
0.0968375	structure inside radius (m)
0.1095375	pipe outside radius (m)
0.1603375	insulation outer radius (m)
0.02946029	coolant flow area (m^2)
0.193675	hydraulic diameter (m)

Cascading Change Example

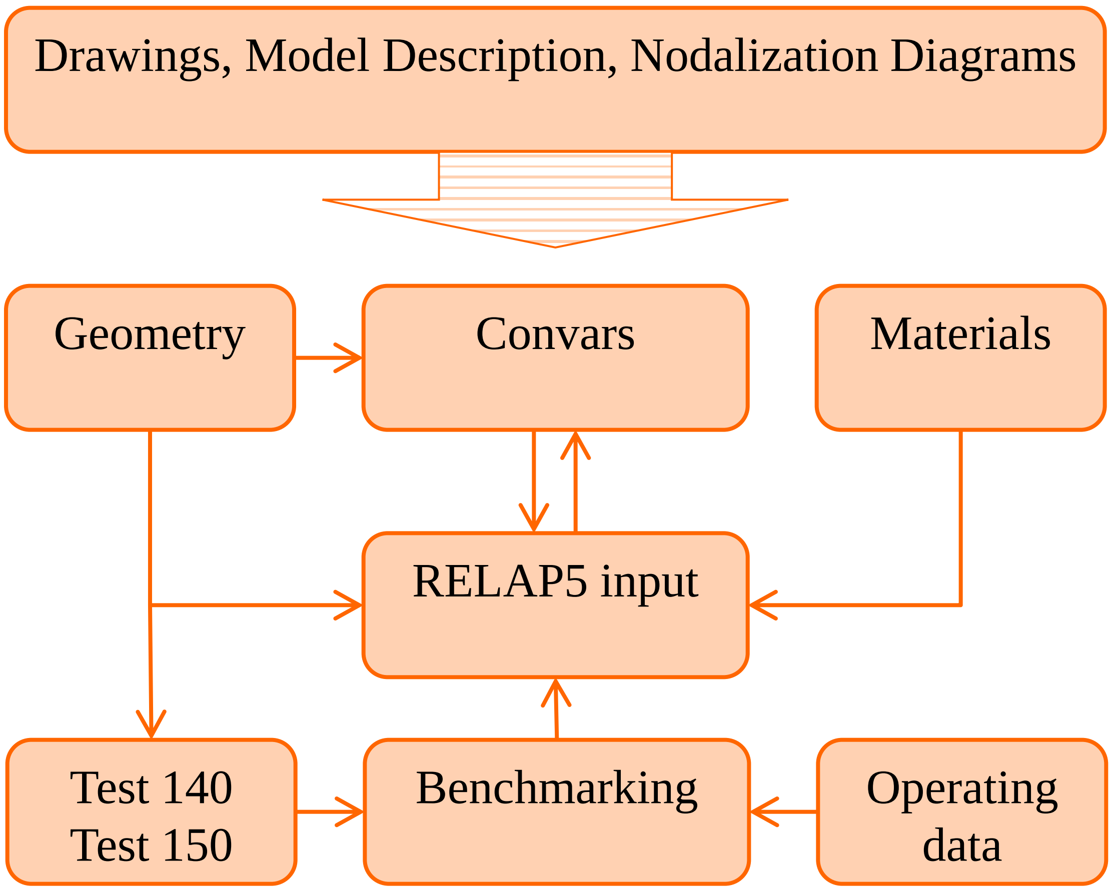
- Coolant channel diameter changes (evolving design or sensitivity study)
- Flow area
- Hydraulic diameter
- Heat structure inner radius
- Heat structure outer radius (maybe)
- Radiation view factors
- Conduction area factors
- Heat structure surface area multipliers in control variables calculating component energy balances

Nuisances

- Linking data between spreadsheets
- Columns need to be wide enough that numbers have spaces in between
- May get lines too long (beyond 80 characters – easily fixed in vi)

Quality Assurance Process - Workflow

- Comments
- Geometry
- RELAP5 input
- Materials
- Convars
- Power
- References
- Benchmarking
- Test 140
- Test 150



Checking Input

- Constants
  - Do they come with a reference?
  - Do they match the reference?
- Formulas
  - Is the form correct?
  - Are the cell references correct?
- Overall structure
  - Is it consistent with the model description document and nodalization diagrams?

fx =2/3*PI()*A628*A633^2

	A	B	C	D	E	F	G	H	I	J	K
618											
619	Steam generator (Component HX-100)										
620	inlet/outlet plenum										
621	23	distance from inlet flange to bottom of tube sheet (in.) [Dwg. 25838, sh. 1, Rev. AB]									
622	0.5842	length/height of inlet plenum fluid volume (m)									
623	20.25	distance from outlet flange to bottom of tube sheet (in.) [Dwg. 25838, sh. 1, Rev. AB]									
624	0.51435	length/height of outlet plenum fluid volume (m)									
625	24	bottom head outer diameter (in.) [Dwg. 25838, sh. 1, Rev. AB, item 8]									
626	1.25	bottom head thickness (in.) [Dwg. 25838, sh. 1, Rev. AB, item 8]									
627	0.3048	outer radius (m)									
628	0.27305	inner radius (m)									
629	Assume the lower head end cap is a cylinder on top of half of an oblate spheroid										
630	6.4375	total height of lower end cap (in.) (height of pass partition) [Dwg. 25838, sh. 1, Rev. AB, item 10]									
631	0.1635125	total height of lower end cap (m)									
632	2:1	semi-elliptical head radius ratio [Dwg. 25838, sh. 1, Rev. AB, item 8]									
633	0.136525	minor radius of spheroid (m)									
634	0.010659214	volume of half spheroid (m^3) {0.5 x 4π/3 x a^2b}				"a" is the major radius, and "b" is the minor radius.					Fixed
635	0.0269875	height of cylindrical portion (m)									
636	0.006321162	volume of cylindrical portion (m^3)									

fx =convars!B$45

	A	B	C	D	E	F	G	H	I
6010	*								
6011	20511800	qcv9500l	sum	1.0	0.0	1			
6012	20511801	0.0	9.414	htrnr	950000100	3.252	htrnr	950000200	
6013	20511802		2.168	htrnr	950000300	2.453	htrnr	950000400	
6014	20511803		9.414	htrnr	950000500	2.453	htrnr	950000600	convars!B$49
6015	20511804		2.453	htrnr	950000700	2.453	htrnr	950000800	
6016	20511805		2.453	htrnr	950000900	2.453	htrnr	950001000	
6017	20511806		2.453	htrnr	950001100	2.453	htrnr	950001200	
6018	20511807		2.453	htrnr	950001300	2.453	htrnr	950001400	
6019	20511808		1.932	htrnr	950001500	1.858	htrnr	950001600	
6020	+		2.044	htrnr	950001700	9.414	htrnr	950001800	
6021	+		5.655	htrnr	950001900				
6022	*								

7564	*							
7565	20530810	es-cbarl	sum	1.0	0.0	1	See convars; a level is missing here.	
7566	20530811	0.0	1.0	cntrlvar	3052	1.0	cntrlvar	3054
7567	20530812		1.0	cntrlvar	3056	1.0	cntrlvar	3058
7568	20530813		1.0	cntrlvar	3060	1.0	cntrlvar	3062
7569	20530814		1.0	cntrlvar	3064	1.0	cntrlvar	3066
7570	20530815		1.0	cntrlvar	3068	1.0	cntrlvar	3070
7571	20530816		1.0	cntrlvar	3072	1.0	cntrlvar	3074
7572	20530817		1.0	cntrlvar	3076	1.0	cntrlvar	3078
7573	20530818		1.0	cntrlvar	3080			
7574	*							

Quality Assurance - Documentation

- Cells confirmed to be correct are highlighted in ***green***
- Cells with confirmed or potential problems are highlighted in ***red*** and annotated to describe the issue or suggest a change
- All flagged cells are reviewed by developer and reviewer together and changed (or not changed) as appropriate
- Changes made at this stage are documented using the "track changes" feature
- These tracked changes are re-reviewed to verify that they have been done and are correct
- Resolution of all flagged cells annotated in the original markup
- Original, markup, and revised copies are retained
- Model description document is edited in a similar way

Summary and Conclusions

- We have developed a RELAP5-3D model of the HTTF facility at Oregon State University
- The model has been developed using spreadsheet-based input file generation that is less error-prone and facilitates tracking design changes
- The model is subject to a rigorous and well-documented quality assurance process
- Further model refinement will occur when plant data become available