April 2016

The RETRAN & VIPRE Newsletter

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RVUG Meeting

The Spring 2016 'RETRAN/VIPRE User Group Meeting' will be held May 24 & 25, 2016, at the Virginian Lodge in Jackson Hole, Wyoming. For additional details visit our website. When making your reservations, mention "RETRAN/VIPRE User Group Meeting" or Zachry/CSA to receive special lodging rates. Meeting sessions will include the following topics:

1. organization activities,
2. reports from code users,
3. maintenance activities,
4. development activities,
5. and presentations.

RETRAN Training

Zachry will be conducting a Basic Training Session on the use of the RETRAN code. The session will be held in Idaho Falls, Idaho on June 20 – 24, 2016. For additional details visit our website.

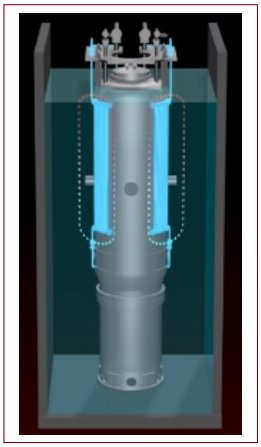
NUPIC Audit

A NUPIC audit is tentatively scheduled for the last week of June.

§ Zachry Group acquires CSA §

NuScale Power joins VIPRE User Group

Utilizing VIPRE-01 in the thermal-hydraulic analysis of its unique light water reactor design, NuScale Power, LLC became one of the recent VIPRE User Group (VUG) members. Since 2000, the Oregon-based company has been developing a first-of-its-kind small modular integral pressurized water reactor (IPWR) in collaboration with Oregon State University, the Idaho National Laboratory, and Nexant. In 2011, Fluor entered as a major investor and partner.



Based on light water reactor technology, the unique design reduces complexity, improves safety, enhances operability, and reduces risks. Each NuScale Power Module™ (NPM) has a thermal capacity of 160 MWt and produces 50 MWe (gross). The design is unique in that a $76'$ x $15'$ cylindrical containment vessel houses the reactor and steam generator. NuScale was the first SMR vendor to engage with the U.S. Nuclear Regulatory Commission, and they are expected to submit their Design Certification Application in 2016.

Since 2012, ZNE/CSA engineers have been providing engineering services to NuScale Power and working with NuScale engineers in several areas including applied research, model development, and thermal-hydraulic analysis support for the NPM design using RETRAN-3D, a nuclear safety thermal-hydraulic transient analysis code, and VIPRE, a steady-state and transient subchannel code.

VIPRE-01 MOD02.6 Summer Release

VIPRE-01 MOD02.6 will be released in early summer 2016. It is supported on UNIX/Linux and Windows platforms.

VIPRE-01 MOD02.6 contains modifications that have been requested by the Viper User Group (VUG) as part of a work scope item, but it also contains corrections for trouble reports. The planned set of user requested modifications are summarized here: Key Mods

VUG members can request VIPRE-01 MOD02.6 by contacting Pam Richardson. For additional details about VIPRE-01 please visit our website.

LaTeX

RETRAN-3D Implicit Two-Region Solution Scheme (Four-Equation Option)

RETRAN-3D has two different two-region nonequilibrium volume (pressurizer) solution methods, an explicit solution and an implicit solution. The explicit scheme can introduce instabilities and inaccuracy when multiple connections to the volume are present. This is exaggerated when the flows are significant, e.g., when the model is used for upper BWR downcomers and PWR head volumes. The explicit solution has generally been adequate for pressurizer applications. The Safety Evaluation Report (SER) identifies conditions of use associated with the explicit solution. The implicit solution method is stable and more accurate for larger time-step sizes when multiple connections are used and the flows are significant. The NRC approved the implicit model for use in the SER.

The current implicit solution method suffers from significantly longer running times than the explicit solution. On average, the implicit solution scheme requires about twice the run time compared to the explicit solution scheme. With two different solution methods, the effort required to maintain the code is double what it needs to be.

A revised implicit solution scheme has been implemented in RETRAN-3D that significantly improves the run time. In addition, the explicit solution method has been removed, leaving a single two-region model solution.

The current RETRAN-3D finite difference balance equations are represented by matrix A containing the coefficients of the balance equations that multiply the vector of unknowns E to give the right-hand side vector G.

Two methods are currently available for setting up and solving the system of equations shown in Eq. (1), depending on model options used. For the standard solution using either the homogenous equilibrium model or a two-phase slip model, the matrix order m is equal to 2Njun+Nvol which might typically be on the order of 200 to 300. If the five-equation model is used, the matrix order m is equal to 2Njun+3Nvol, which might typically be on the order of 350 to 500. This solution option is capable of solving a six-equation model or the five-equation model with noncondensible gas.

$$\begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{bmatrix} \begin{bmatrix} e_1 \\ \vdots \\ e_m \end{bmatrix} = \begin{bmatrix} g_1 \\ \vdots \\ g_m \end{bmatrix}$$

Equation (1)

Matrix A is stored as a sparse matrix where only nonzero or potentially nonzero elements are stored. The solution for Eq. (1) takes advantage of the structure of A, where much of it can be tridiagonal. This allows for an efficient matrix solution to be implemented, which significantly reduces the CPU time required to solve the coupled equation set.

The explicit two-region nonequilibrium model solved both the continuity and energy equations for the liquid and vapor regions outside the matrix equations shown above. Old time-step values for all of the convective quantities were used to evaluate the equations. At the same time, the mixture continuity and energy equations for two-region nonequilibrium volumes were solved as part of the standard solution. The SER condition related to the explicit pressurizer model is associated with concern that the explicit region masses and energies may not sum to the mixture values determined as part of the matrix solution. On the other hand, the implicit solution currently uses the six-equation form of Eq. (1) where m is equal to 2Njun+3Nvol and 3 volume balance equations can be solved for each volume. For a two-region nonequilibrium volume, additional volume equations are solved for vapor region mass and energy.

A much faster running implicit two-region nonequilibrium solution has been implemented by adding rows at the bottom of the three- or four-equation matrix to solve for the vapor region balance equations, rather than using the six-equation solver. This is illustrated by the augmented matrix shown in Eq. (2).

$$\begin{bmatrix} \begin{pmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{pmatrix} \begin{pmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{pmatrix} \\ \begin{pmatrix} c_{11} & \cdots & c_{1m} \\ \vdots & \ddots & \vdots \\ c_{n1} & \cdots & c_{nm} \end{pmatrix} \begin{pmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nn} \end{pmatrix} \end{bmatrix} \begin{bmatrix} \begin{pmatrix} e_1 \\ \vdots \\ e_m \end{pmatrix} \\ \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix} \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} g_1 \\ \vdots \\ g_m \end{pmatrix} \\ \begin{pmatrix} h_1 \\ \vdots \\ h_n \end{pmatrix} \end{bmatrix}$$

Equation (2)

Matrix C is comprised of a vapor region continuity and vapor region energy equation coefficients that are dependent on the change in junction mass flow rate and slip velocity and volume internal energy contained in vector E for each two-region nonequilibrium volume (pressurizer).

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RETRAN-3D Implicit Two-Region Solution Scheme (cont.)

Matrix D contains the coefficients for the vapor region mass and energy coefficients that are dependent on the change in vapor region mass and energy contained in vector F, and vector H contains the right-hand side of the vapor region mass and energy balance equations. The order of matrix D is n, which is equal to 2Nprz. A typical value of n would be 4 and may never exceed 6, so matrices B, C and D are generally quite small compared with A.

Solver

Equation (1) is solved using a sparse matrix block elimination scheme described in the RETRAN-3D Theory and Numerics Manual – Volume 1 – Section VIII. A block elimination scheme was used whereby the elements below the diagonal are eliminated and a unity diagonal is obtained. A reverse sweep from the bottom to the top eliminates the elements above the diagonal. This gives the solution in vector G.

The solution to Eq. (2) can be obtained similarly. As the elements below the diagonal are eliminated, operations are performed on vector G. Similar operations must be performed on the columns of matrix B. The operations on the B column vectors were added to the general solution scheme used when the two-region model is used. This follows the modifications made to the right-hand side vector G. This elimination process changes the elements in the B matrix and G vector as indicated by the primes in Eq. (3).

$$\begin{bmatrix} \begin{pmatrix} 1 & \cdots & a'_{1m} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix} \begin{pmatrix} b'_{11} & \cdots & b'_{1n} \\ \vdots & \ddots & \vdots \\ b'_{m1} & \cdots & b'_{mn} \end{pmatrix} \\ \begin{pmatrix} c_{11} & \cdots & c_{1m} \\ \vdots & \ddots & \vdots \\ c_{n1} & \cdots & c_{nm} \end{pmatrix} \begin{pmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nn} \end{pmatrix} \end{bmatrix} \begin{bmatrix} \begin{pmatrix} e_1 \\ \vdots \\ e_m \end{pmatrix} \\ \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix} \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} g'_1 \\ \vdots \\ g'_m \end{pmatrix} \\ \begin{pmatrix} h_1 \\ \vdots \\ h_n \end{pmatrix} \end{bmatrix}$$

Equation (3)

Next, operations are performed to eliminate the elements of matrix C, which result in modified matrix D and right-hand side vector H. This is done by multiplying the element in C that is to be eliminated times the row above that contains 1 on the diagonal. Note that the diagonal is not actually set to one to save operations; it is assumed to be one. The row is then subtracted from the corresponding row in C. There is no need to set or calculate the element being eliminated, but any column where there is a nonzero element above the diagonal will modify the corresponding column in C. The same is true for matrix D and vector H. This process is used to eliminate all nonzero elements in each row of C. As this is done, elements in D and H are also changed. The resulting equation is

$$\begin{bmatrix} \begin{pmatrix} 1 & \cdots & a'_{1m} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix} \begin{pmatrix} b'_{11} & \cdots & b'_{1n} \\ \vdots & \ddots & \vdots \\ b'_{m1} & \cdots & b'_{mn} \end{pmatrix} \\ \begin{pmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{pmatrix} \begin{pmatrix} d'_{11} & \cdots & d'_{1n} \\ \vdots & \ddots & \vdots \\ d'_{n1} & \cdots & d'_{nn} \end{pmatrix} \end{bmatrix} \begin{bmatrix} \begin{pmatrix} e_1 \\ \vdots \\ e_m \end{pmatrix} \\ \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix} \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} g'_1 \\ \vdots \\ g'_m \end{pmatrix} \\ \begin{pmatrix} h'_1 \\ \vdots \\ h'_n \end{pmatrix} \end{bmatrix}$$

Equation (4)

Next, the modified D' matrix is solved for the vapor region mass and energy changes (vector F). At this point the system of equations is effectively given by Eq. (5), where the solution for the two-region volume vapor region mass and energy changes are in vector H" as shown below.

$$\begin{bmatrix} \begin{pmatrix} 1 & \cdots & a'_{1m} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix} \begin{pmatrix} b'_{11} & \cdots & b'_{1n} \\ \vdots & \ddots & \vdots \\ b'_{m1} & \cdots & b'_{mn} \end{pmatrix} \\ \begin{pmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{pmatrix} \begin{pmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix} \end{bmatrix} \begin{bmatrix} \begin{pmatrix} e_1 \\ \vdots \\ e_m \end{pmatrix} \\ \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix} \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} g'_1 \\ \vdots \\ g'_m \end{pmatrix} \\ \begin{pmatrix} h''_1 \\ \vdots \\ h''_n \end{pmatrix} \end{bmatrix}$$

Equation (5)

Finally, the solution contained in vector H" is multiplied by each row in matrix B' and the resulting vector is subtracted from G' (actually done one row at a time). This

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RETRAN-3D Implicit Two-Region Solution Scheme (cont.)

elimination step for B' does not use matrix A and only modifies vector B. After performing the steps described above, the system of equations is reduced to

$$\begin{bmatrix} \begin{pmatrix} 1 & \cdots & a'_{1m} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix} \begin{pmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{pmatrix} \begin{pmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{pmatrix} \end{bmatrix} \begin{bmatrix} \begin{pmatrix} e_1 \\ \vdots \\ e_m \end{pmatrix} \\ \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix} \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} g''_1 \\ \vdots \\ g''_m \end{pmatrix} \\ \begin{pmatrix} h''_1 \\ \vdots \\ h''_n \end{pmatrix} \end{bmatrix}$$

Equation (6)

Solution for the vector of unknowns E is obtained by using the backsubstitution or the normal solution scheme.

Run-Time Improvements

Several large system cases were tested with the revised implicit two-region volume solution scheme. All cases were run with old implicit solution scheme, revised implicit solution scheme using the four- and five-equation options. The run time for all cases is tabulated in Table 1.

Table 1. Test Cases Run Time

Case	Utility	Base Runtime	4eq Runtime	5eq Runtime	4eq % Diff	5eq % Diff
DSLB	Duke	6626.52	3467.50	8258.68	-47.67	24.63
FPL_ELAP	FPL	9032.38	5175.01	10654.30	-42.71	17.96
IP3	Entergy	3815.16	1993.68	4039.66	-47.74	5.88
LSLB	Duke	583.32	318.84	612.32	-45.34	4.97
MFLB_LOOP	Dominion	926.88	514.69	979.56	-44.47	5.68
WC5.2	WCNOC	1620.21	682.75	1706.14	-57.86	5.30
TOP Peaked Pwr	WCNOC	1322.44	727.17	1383.29	-45.01	4.60
Total		23926.91	12879.64	27633.95	-46.17	15.49

Note: Units in CPU seconds

The revised implicit solution scheme, when used with four-equation option (NUMRCS = 2) cuts the run time in half. Whereas, the same scheme used with the five-equation option (NUMRCS = 3) adds about 10% to 20% to the run time compared to the old implicit solution scheme. The only time the user would need to use NUMRCS of 3 is when the five-equation option is used or noncondensables are specified. Users are no longer required to use NUMRCS = 3 to run the implicit solution scheme.

In summary, the revised solution scheme improves the run time for the implicit solution scheme significantly. It also frees matrix space to allow an option to allow noncondensables flow to be included with the nonequilibrium model in the future (currently not implemented in RETRAN-3D). The revision also simplifies the maintenance of the two-region model in that the separate explicit model is removed and no longer requires parallel maintenance effort.

RETRAN Visualization Tool

The RETRAN Visualization Tool (RVT) assists RETRAN users in their review and interpretation of RETRAN analysis results. The RVT provides various visualization tools for graphically presenting the results of a RETRAN simulation. It also provides for simple and quick access to most parameters computed by RETRAN.

Reviewing and understanding RETRAN results has typically been done by reviewing output files and plotting a few parameters. Over the years, various improvements have occurred, and recently Excel became a popular tool for viewing RETRAN results. However, Excel can be inefficient and cumbersome when the size of the data files becomes large (greater than 75 to 100 parameters and more than 500 time points). With the improvements in software and computer hardware, something new and better has evolved. The RVT, a quick, intuitive, Java-based RETRAN-specific visulization tool is the result. It provides a means for a user to use an existing nodalization diagram to build a 'visualization model' for their plant using simple drawing tools.

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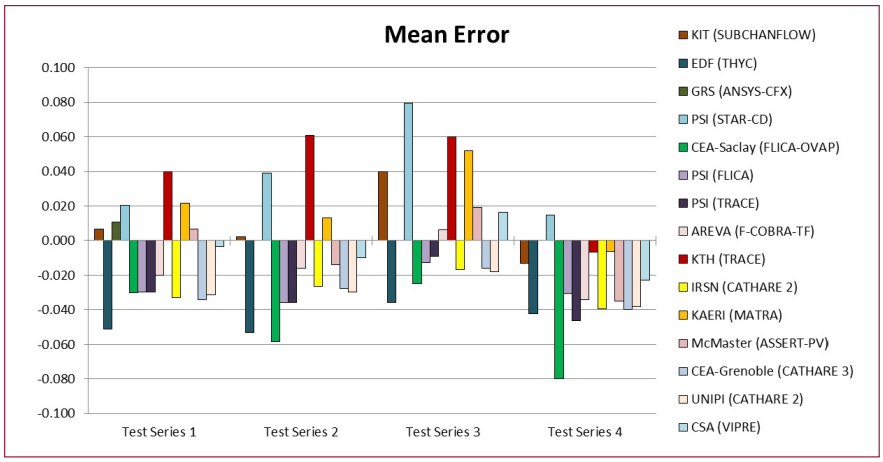
PSBT Benchmark with VIPRE-01

In 2012, CSA was funded by the VUG to participate in an international benchmark on pressurized water reactor subchannel and bundle tests using VIPRE-01. The purpose of the benchmark was to evaluate the strengths and weaknesses of current thermal-hydrauic codes and to encourage development of the next generation of computational approches. Detailed reports of the PBST benchmark were recently released; they are available online at the OECD/NEA website.

Overall, VIPRE-01 performed well in comparison to several Computational Fluid Dynamics (CFD), system, subchannel, and porous media codes. For example, the figure below compares the void fraction mean error associated with steady-state simulations for four different "Test Series"(i.e., assemblies), including center (typical), center (thimble), side, and corner.



(cf. page 46 of "Volume II: Benchmark results of phase I - Void distribution")

§ Tech Tips §

VIPRE-01 Time-Step Control

In transient calculations, the user must specify the time-step size that will be used in the code by specifying a constant step size or by exercising options for variable time-step size using the automatic time-step adjuster. Large time steps are used where the forcing function is not changing rapidly, and progressively finer steps are employed where more detail is required.

Therefore, it is suggested that a simplified model (few channels and rods) be run through the transient with a fixed time step to investigate the need for and possible consequences of the automatic time-step adjuster.

Food for Thought . . .

"I would rather have questions that can't be answered than answers that can't be questioned."
~Richard Feynman (1918-1988), American theoretical physicist

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If you are interested in previous issues of 'The RETRAN & VIPRE Newsletter' or you would like to contribute an article, please visit our Newsletter web page.

Key Mods

RETRAN-3D (next release)

1. Added McAdams free convection correlation for surface heat transfer.
2. Logic to allow custom user-supplied headings for minor edit variables.
3. Option to specify slip model for each junctions using junction input data cards.
4. Edits for noncondensable mass error, total mass error, and energy error.

VIPRE-01 (next release)

1. User-specified DNBR edit.
2. Enhanced pressure drop components edit.
3. Plot file generation.

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Exelon joins VUG

In January, Exelon became the most recent member of the VIPRE User Group. A Fortune 150 company, Exelon works in power generation, energy sales, transmission and delivery.

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