INL/RPT-22-70259-Revision-0

2021 RELAP5-3D Annual Report

March 2023

Connie Stevens

Changing the World's Energy Future

Idaho National Laboratory

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RELAP5-3D

Reactor Excursion & Leak Analysis Program

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2021 Annual Report

SUMMARY OF PROGRAM NEWS, CODE DEVELOPMENT, IRUG MEETING, AND USER PROBLEM STATUS

Idaho National Laboratory

Table of Contents

Notes from the Program Manager

DEVELOPING FOR CURRENT AND NEXT GENERATION NUCLEAR REACTORS

Light Water Reactors (LWRs) were the initial focus of RELAP5-3D and an extensive experiment database allowed RELAP5-3D modeling and simulation to mature and become one of the premier international system codes. LWRs design changes may have slowed during the last decade, but RELAP5-3D modeling continues to evolve. The RELAP5-3D Program consistently seeks to integrate more accurate modeling and modeling for new physics. This pursuit includes LWRs and gas-cooled reactors, but also next generation nuclear reactor designs that feature molten salt and sodium-cooled. The RELAP5-3D Program is not resting on its laurels of yesterday, instead it is considering new opportunities to increase code capability and value to license holders. An example of increasing value was the simultaneous Beginner and Advanced Training at this year's IRUG meeting and not restricting license holders to an alternating Beginner/Advanced Training cycle. Additional options are planned that will increase the value of the RELAP5-3D license.

FINANCIAL NEWS

Years have passed since the last increase in the RELAP5-3D license fee. We understand that software investment is a critical component to business success. Your support of RELAP5-3D is highly valued, and we are working diligently to increase that value. The cost of business has increased and so must the RELAP5-3D license fee. In most cases, the fee difference is modest. The new fee schedule and an explanation of benefits are provided in this annual report.

OPERATING HIGHLIGHTS

The RELAP5-3D Program has a strategic goal of better integration with our license holders and stakeholders. Stakeholders are the reason that RELAP5-3D has remained an important mainstay in nuclear reactor modeling and simulation. To better respond to your needs and receive your input on the code's direction, a RELAP5-3D project coordinator was hired. Mrs. Connie Stevens will be your active liaison to the RELAP5-3D program manager and development team. Please look forward to hearing from her and sharing with her how we can better serve you.

PRODUCT QUALITY

RELAP5-3D developers are certified with ASME NQA-1 training and perform code development tasks according to defined quality plans, procedures, and work instructions. The RELAP5-3D code is certified to the ASME NQA-3 standard. The program recently initiated its planned three-year review of all quality documents and processes. RELAP5-3D analyses performed under Strategic Partnership Projects, Cooperative Research and Development Agreements, and Gateway for Accelerated Innovation in Nuclear vouchers follow established work instructions and are subject to independent review to ensure and document the quality of those analyses.

ACADEMIA

RELAP5-3D has a special license agreement with accredited universities, so the next generation of nuclear thermal hydraulics engineers gain valuable experience with the industry's premier system code. The Program has also initiated an effort to strengthen partnerships in areas such as senior undergraduate design team sponsorship, strategic numerical-methods curriculum, and intern research opportunities. Furthermore, the Program has targeted consistent post-doctoral positions and is seeking a joint appointment with an established computer science and engineering research professor.

COMPETITION

Some of the strengths of the RELAP5-3D code are its large experiment database, breadth and depth of functionality and flexibility, high performance on non-high performance computing platforms, ASME NQA-3 certification, straightforwardness in achieving Commercial Grade Dedication, customer support, and total cost of ownership.

The primary RELAP5-3D code competitors include INL's RELAP7, Argonne National Laboratory's SAS4A/SASSYS-1, Nuclear Regulatory Commission's RELAP5/MOD3, and the INL MOOSE-Based Thermal Hydraulics Module. Other potential competitors include startup firms and solutions produced in-house by the end users. Our current and potential future competitors may have greater financial, technical, marketing, and other resources than the Program. It is feasible these competitor advantages may cause the Program to lose market share.

HUMAN CAPITAL RESOURCE

The longevity of the RELAP5-3D Program is a testament to the commitment of our people. Without question, people are the Program's most important investment and its greatest asset. The COVID-19 pandemic and the resurgence of nuclear energy changed both the work environment and expectations. However, the Program's success remains intimately connected to its ability to attract, develop, incent, and retain a diverse population of talented, qualified, and highly skilled employees. The Program is exploring new strategies for recruitment and retention; these strategies focus on promoting diversity, inclusion and belonging, surveying employee satisfaction, and engagement.

DIVERSITY AND INCLUSION

Consistent with Idaho National Laboratory's strong position on diversity, the RELAP5-3D Program places significant value on the diversity of perspective and experience as they pertain to code development, verification and validation, quality management, and modeling and simulation standards. The Program has diversity in its management, developers, interns, and post doctorate candidates. The Program continues to pursue diversity when seeking highly qualified and talented employees.

LOOKING AHEAD

A new version of the code is scheduled for release in 2023. There are several interesting features in this new version, with a few briefly described in this annual report. As mentioned above, there are several new initiatives to give the code more utility to its stakeholders. We are excited about the future of nuclear reactors and the role that RELAP5-3D will play in that future.

Theron D. Marshall
RELAP5-3D Program Manager
October 29, 2022

Financial Summary

The following table outlines the RELAP5-3D membership levels and associated benefits.

MEMBERSHIP	INSTALLATION SUPPORT (HRS)	DEVELOPER SUPPORT (HRS)	PRIORITIZED USER PROBLEM TICKETS[A]	USER MANUALS	SOURCE ACCESS[B]	IRUG MBRSHP[C]	IRUG REGIST[D]	SUBCONTRACTOR OBJECT SHARING[E]	LOCAL LICENSE[F]
Diamond	15	60	10	User/Theory Manuals	✓	✓	2	✓	✓
Gold	10	30	5	User/Theory Manuals	✓	✓	-	✓	✓
Limited Developer	5	15	2	User/Theory Manuals		✓	-		
Commercial – Multi-user	3	5	-	User Manual		✓	-		
Commercial – Single-user	3	3	-	User Manual		✓	-		
Commercial – Limited Use									
Academic	3	3	-	User Manual		✓	-		

Notes: [a] Number of prioritized user problem tickets per license agreement period. Prioritized user problem tickets receive a proposed solution within five business days.
[b] Requests for source must be approved by INL's Code Oversight Group and export control department.
[c] IRUG membership is required to attend IRUG seminars and training.
[d] Diamond members are provided one complimentary IRUG registration.
[e] Diamond and Gold members are allowed to share executables of their source with one subcontractor, subject to an approved license agreement.
[f] Remote and local RELAP5-3D licenses are separate licenses.

RELAP5-3D Membership Fee Structure

LICENSE LEVEL	LICENSE FEE (USD) REMOTE RELAP5-3D DOMESTIC	LICENSE FEE (USD) REMOTE RELAP5-3D INTERNATIONAL	LICENSE FEE (USD) LOCAL RELAP5-3D DOMESTIC	LICENSE FEE (USD) LOCAL RELAP5-3D INTERNATIONAL
Diamond	-	-	68,000	84,000
Gold	-	-	37,700	63,770
Limited Developer	20,000	38,000		
Commercial – Multi-user	9,700	18,420	10,900	19,620
Commercial – Single-user	6,630	13,170	7,630	14,170
University	0	0	0	0

Notes: The Limited Developer license provides developer access to a restricted set of RELAP5-3D subroutines to incorporate user-developed modification and have a corresponding executable generated. The Limited Developer license is restricted to Remote RELAP5-3D.

Program Business Activities

REMOTE RELAP5-3D

Remote RELAP5-3D was created at the direction of the U.S. Department of Energy (DOE) because of concerns for both U.S. security and INL intellectual property protection. DOE classifies RELAP5-3D as a 10 CFR 810 code because of its ability to model current and advanced designs for nuclear power plants. Previously, local installation of the RELAP5-3D executable was the default. However, DOE current guidance is for users to execute RELAP5-3D on the INL HPC, which is termed, "Remote RELAP5-3D."

There are many benefits of Remote RELAP5-3D available to the International RELAP5 User Group (IRUG) members. Several of these benefits include access to recent code version, multi-core CPUs, large system memory, and 1 TB disk space. Remote RELAP5-3D is available 24-hours a day, 7-days a week from any internet-connected computer. Access is via an INL HPC account that is requested via the INL Nuclear Computational Resource Center (NCRC) website, https://inl.gov/ncrc/.

Written by Dr. George Mesina

RELAP5-3D LICENSE AGREEMENTS

RELAP5-3D license agreements have transitioned from the past. A license is valid for one year and requires the license holder's request for renewals. In the near future, multi-year licenses are envisioned, but currently only one-year licenses are available. The license agreement process is initiated via the NCRC website, https://inl.gov/ncrc/.

New and renewal license requesters are provided a copy of the standard RELAP5-3D license agreement. If there are no revisions to the agreement required by the requesters' legal team, then the requesters sign the agreement and return it to the Agreements Administrator (agradmin@inl.gov). Upon receipt of the signed agreement, the Agreements Administrator will forward an invoice for the annual license fee. Upon invoice payment, the license agreement will be executed, and a license file provided. In situations where revisions to the standard RELAP5-3D license agreement are required, discussions will be held between the requesters' and INL's legal teams to determine an agreement that fulfils both organization's legal requirements. Review and discussions by legal teams add additional time to the license agreement approval process.

There are three types of RELAP5-3D licenses:

Academic – code is used only for classroom and student design activities. No commercial project work is authorized.

Government Use – code is used only to support project work at national laboratories and federal organizations. No commercial project work is authorized.

Commercial Use – code is used to perform commercial project work.

Using the RELAP5-3D code outside of its license agreement is just cause to terminate the license.

Written by Mrs. Connie Stevens

RELAP5-3D NEW USER REQUESTS

Pursuant to DOE directives, every RELAP5-3D user is required to be vetted. This vetting process consists of establishing the user's identity and intended use of the RELAP5-3D code. A new user request is currently a two-step process. The first step is to request an INL HPC account using the INL NCRC website https://inl.gov/ncrc/. When submitting the HPC account request, select the RELAP5-3D Program Manager (Theron Marshall) as the account sponsor. When NCRC forwards the account request to the Program Manager, it will be approved as an HPC user. Please note that the HPC account does not commit the user to use INL's HPC, instead it is a method of registering an INL software user.

After approval for an HPC account is received, the user will login to the NCRC system with the provided login credentials and request access to the RELAP5-3D code. In this request, users need to provide a detailed description of the intended use of the code. Vague or incomplete descriptions will result in a considerable delay in the approval of the request. In addition, the personal information requested must be provided to verify the user's identity. Personal information is Official Use Only and is protected with high security and limited access. The user will be contacted if the identity information is incomplete, but this process may also result in a considerable delay in approval of the request. The INL Code Oversight Group is a special group of subject matter experts that review all new user requests for their stated use of the code.

This review is in conjunction with the INL Export Control review of the new user's identity. The new user review and approval can average four to six weeks. Users with international work experiences will require a longer processing time.

Written by Dr. Theron Marshall

RELAP5/MOD3 PROMOTION

The International RELAP5 User Group (IRUG) welcomes members of both RELAP5-3D and RELAP5/MOD3. There are many advances in RELAP5-3D that I, as Program Manager, want to make available to our RELAP5/MOD3 colleagues. The new code release scheduled for 2023 contains significant development in the code.

U.S. national laboratories qualify for a no-cost Government Use license for RELAP5-3D. National laboratory individuals should contact the Agreements Administrator (agradmin@inl.gov) for licensing details or the Program Manager, R53DProgram.Manager@inl.gov for technical details.

RELAP5/MOD3 users qualify for a special one-time, RELAP5-3D annual license fee. This special license fee provides full access to the code at a notable savings. Renewals after the one-year period will be at the normal license fee. The deadline for requesting this special license fee is June 1, 2023. Please contact the RELAP5-3D project coordinator, R53DProject.Coordinator@inl.gov, for additional information.

Written by Dr. Theron Marshall

Code Development Activities

DEVELOPMENT OF POINT REACTOR KINETIC MODEL FOR MOLTEN SALT REACTOR

A dedicated reactor kinetics model was added to RELAP5-3D. Different to static fuel nuclear reactors, the Molten-Salt Reactor (MSR) system comprises a liquid type of fuel resolved in the liquid metal eutectic coolant. Due to these characteristics, the flow of the delayed neutron precursors in the liquid fuel highly affects the generated reactor power and the need for a different reactor kinetics model. Based on a wide literature review, the delayed neutron precursor equation was modified by introducing a liquid-fuel travel time and reactivity biased term in the reactor core and loop area [1]. The verification and validation of the new model is being performed with available experiment data.

Written by Dr. Yong-Joon Choi

[1] N. Suzuki and Y. Shimazu. 2008. "Reactivity-Initiated-Accident Analysis Without Scram of a Molten Salt Reactor," Journal of Nuclear Science and Technology 45(6): 575.

HELIUM-3 PROPERTIES

Helium-3 properties were added to RELAP5-3D as a new non-condensable gas option. This update makes Helium-3 the 12th non-condensable gas that can be accessed through card 110. The keyword is 'he3'. The new properties have been implemented in 'rnoncn.F' and include thermal conductivity, viscosity, density, and specific heat. Proper implementation of the he3 properties was verified comparing RELAP5-3D calculation results to analytical calculations for various shock tube scenarios. RELAP5-3D code outputs for he3 thermal conductivity, viscosity, density, and specific heat at different temperatures and pressures were directly compared with the implemented functions. In addition, RELAP5-3D calculated shock tube pressure, temperature and density ratios, as well as the shock wave velocity were compared to analytic solutions for he3 for various shock tube scenarios (i.e., different high to low pressure ratios and different initial gas temperatures).

Written by Dr. Aaron Epiney

BEST ESTIMATE PLUS UNCERTAINTY

The Risk-Informed Systems Analysis (RISA) Pathway primarily uses the probabilistic safety assessment (PSA) approach to reduce conservatisms in Light Water Reactor (LWR) safety margins. A complementary approach that could further reduce unnecessary conservatisms is to combine the PSA approach and uncertainty analysis methodologies to cover multi-physics phenomena. The RISA Pathway is exploring the Best-Estimate Plus Uncertainty (BEPU) methods in its industry engaged demonstration projects. Figure 1 shows the benefit from BEPU in that the BEPU conservative value is less than the Appendix K value; thereby a justifiable and reproducible reduction in conservatism.

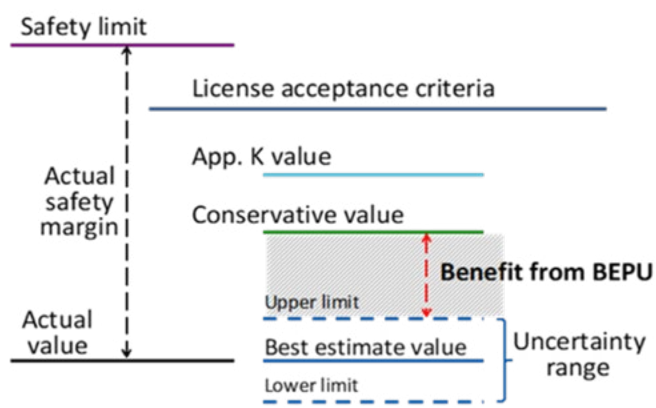


Figure 1. Comparison of safety margins between Appendix K, conservative and BEPU.

One of the outcomes of the industry engagement has been the upgrading of RELAP5-3D, the best estimate thermal-hydraulics code, to allow quantifying uncertainties from major physical phenomena occurring during the reflood phase of a Loss of Coolant Accident scenario.

RELAP5-3D was modified to allow the code users to perturb from the input deck some of the main physical parameters of the closure relations called by the code during simulation of the reflood phase.

Code users can now perturb: system interfacial friction coefficient, system interfacial heat transfer coefficient, heat structures: transition and film boiling heat transfer coefficients—to gas and to liquid, and Interfacial heat transfer coefficient for dry and wet wall conditions for pipe components.

The new features were tested on two sets of the FLECHT-SEASET experiment and predictions are shown in Figure 2. Additional validation using the FEBA experiment data is ongoing.

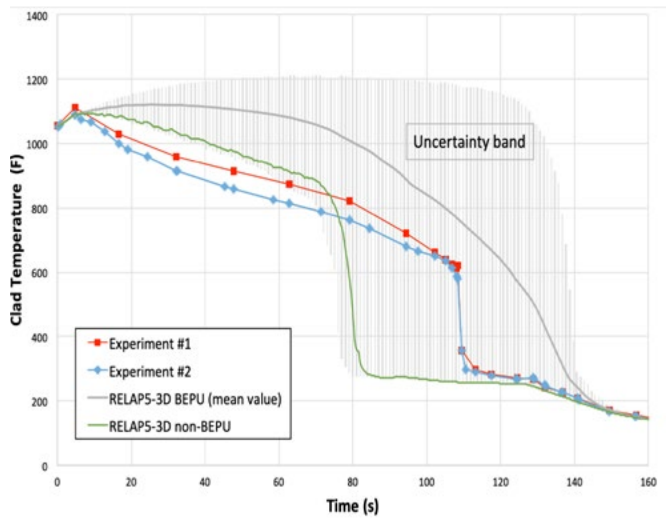


Figure 2. Cladding temperature behavior and uncertainty band at upper part of core, FLECHT-SEASET experiment.

Written by Dr. Carlo Parisi

DISSOLVED GAS MODEL

The Dissolved Gas Model (DGM) adds the capability to model non-condensable gas (NCG) solubility to RELAP5-3D. By definition, a NCG has a critical temperature higher than any temperature reachable during the transient calculation. Thus, it must occur either in the gas phase or in solution in the liquid phase. Similar to RELAP5's existing boron concentration tracking model, for the liquid phase, DGM creates a conservation of solute (continuity) equation for each NCG. For the gas phase, it requires a total continuity equation for the NCGs. DGM also makes use of Henry's Law of Solubility, which states that the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid.

With allowance for up to five dissolved gas concentration equations and up to four gas specie, implementing DGM required new modules, storage arrays, subroutines, and revisions to existing code. The most difficult work involved an overhaul of the coding that creates and solves the Jacobian matrix.

Verification of the DGM addition was performed using a quantitative test suite comprised of 4,180 input cases. All these input cases produced predicted results that agreed.

Written by Dr. George Mesina

METAL-WATER REACTION MODEL

The capability of modeling a thin coating layer to the outside of fuel cladding was added to RELAP5-3D. This coding change affects only cylindrical heat structures. The coating layer is designed to protect the fuel cladding from oxidizing and degrading under high temperature conditions. This oxidation reaction is of concern because it weakens the Zirconium cladding and can increase the fuel temperature. The coating's presence means that the coating reacts instead of the cladding. A slow reacting coating material should protect the fuel cladding.

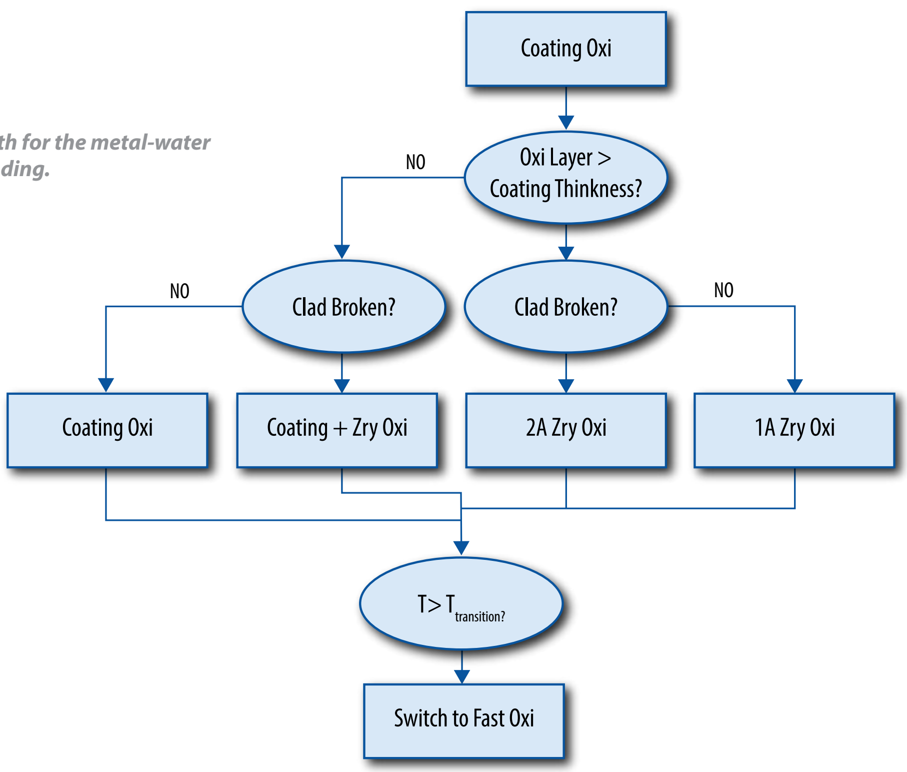
A correlation developed by Cathcart et. al. [2] is used to model the metal-water reaction model in RELAP5-3D. This default correlation was developed for the Zirconium-Steam reaction. The coding has been generalized to allow the user to model coolant-structure chemical interactions for which the parabolic rate law applies. Additional user input was added to allow specifying a transition temperature for the cladding parameters. This input only allows the user to specify a transition reaction rate constant.

The logic path for the metal-water reaction coding is shown in Figure 3. One potential logic path is described here. When a coating layer is applied to the cladding, the coding first checks if the coating has oxidized through the entire thickness. If that is the case, then the code will switch to performing the metal-water reaction calculations for the cladding material only. If the clad has ruptured, then the metal-water reaction will be calculated for both the inner and outer surfaces of the cladding. If the outer surface heat structure temperature is greater than the specified transition temperature, then the coding will switch to using the high-temperature parameters for the calculations. Other logic paths behave as shown in Figure 3.

Written by Mr. Nolan Anderson

[2] J. V. Cathcart, R. E. Pawel, R. A. McKee, R. E. Druschel, G. J. Yurek, J. J. Campbell, S. H. Jury. 1977. "Zirconium Metal-Water Oxidation Kinetics. IV. Reaction Rate Studies." [BWR:PWR], ORNL/NUREG-17, TRN: 77-017423.

Figure 3. Logic path for the metal-water reaction model coding.



User Reported Problems Status

This report documents the user-reported problems that have been submitted between September 2019 and October 2021. In addition, any work that has been performed relating to these user problems is documented.

During this time there were 37 new user problems submitted. Nine of the new user problems have been resolved, one is currently in-work, and the remainder are currently listed as on-hold. Several of the on-hold user problems have a solution already in place that will be implemented before the next code release.

User problems 21012 through 21021 relate to the addition of the dissolved gas model into RELAP5-3D. These user problems will be resolved before the next code release.

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
19006	**Problem Description.** The control variable controlled heat flux as a function of time is not working. Using Word 3 of the 1CCCG501-99/1CCCG601-99 cards of the heat structure input with the -2xxxx option for control variables is not working. There was no change in results when values were modified. There is no error message reported, but using it has no effect. **INL Notes.** The option works but must be input in SI units. Updated the manual accordingly.	Resolved
19007	**Problem Description.** An input deck was failing due to a memory corruption. The transient runs to completion but fails when deallocating space at the end of computation. **INL Notes.** Module listmod.F found an if test that was using the wrong index. In routine listBuild there is a section for a Varying Volume. The if test uses index i for the btest(cmp(i)%cmpopt,2) test, but should be using index icmp instead. This change corrected the observed issue.	Resolved
19008	The code did not transition from nucleate boiling conditions to single phase heat transfer. The wall temperature does not cool down to the fluid temperature, but instead to the saturation temperature. Coding added in version 4.3.4 for low flow subcooled boiling causes the issue. Coding forces the macroscopic convection term from the Chen correlation hmac to 0.0 because it is in low flow conditions. Coding should not be accessed for this problem because fluid temperature is much lower than saturation conditions. Removed the line setting the hmac term to 0.0 and the problem now functions as expected.	Resolved
20004	**Problem Description.** Received a RELAP failure/crash when using a multi-junction connecting a pipe cell to a Time Dependent Valve (TDV) representing the parallel paths of a perforated end cap. When the user attempted to model 37 parallel holes, the failure occurred until the total number of connections was reduced to 20 or lower. The first file MultiJunc_A.i is a model with a 23 connection multi-junction (component 6) between components 5 and 7. This model failed for the user but was successfully run when connections were reduced to 22 or less. The second file MultiJunc_B.i is a model with a 22 connection multi-junction (component 6) between components 5 and 7, and a 3 connection multi-junction (component 16) between components 15 and 17. **INL Notes.** In subroutine TRNSET.F a temporary list vector lvtmp was sized too small. It was sized to the total number of volumes multiplied by 2. The size was changed to the total number of junctions connected to time-dependent volumes multiplied by 2, which was the appropriate size.	Resolved

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
20006	**Problem Description.** A minor error was found in Appendix A, Volume 2 of the 442 Manual. Section 7.7.1 states, "The wall friction must be turned on (f = 0) in the turbine volume in the main flow direction and in the crossflow direction if a steam extraction or moisture separator junction is specified. The rod bundle interphase friction flag must be turned off (b = 0) in the turbine volume." However, Section 7.7.5 states, "The digit f must be entered as 1 for a TURBINE component." Section 7.7.5 is correct. If f = 0 in Component 800, which has an extraction junction, in turbine9.i the code fails on input. **INL Notes.** Section 7.7.1 was changed to read, "wall friction must be turned off (f=1)."	Resolved
20008	**Problem Description.** Reactivity variables added to RELAP5-3D for the Krylov nodal kinetics solver are not described in the input manual. The following descriptions are to be added to the next version of the manual: RKORHO 0 Total reactivity from nodal kinetics ($) RKORHONL 0 Nodal leakage reactivity component from nodal kinetics ($) RKORHOCR 0 Control rod reactivity component from nodal kinetics ($) RKORHOBN 0 Boron reactivity component from nodal kinetics ($) RKORHOTM 0 Moderator temp. reactivity component from nodal kinetics ($) RKORHODM 0 Moderator density reactivity component from nodal kinetics ($) RKORHOTF 0 Doppler reactivity component from nodal kinetics ($) RKORHOXS 0 Xenon/Samarium reactivity component from nodal kinetics ($) In the manual description, these reactivity variables are only calculated when using the Krylov nodal kinetics solver (Card 30000003, Word 17 set to 1); they are not calculated for the line successive over-relaxation (LSOR) LSOR solver or for the point kinetics solver. **INL Notes.** The input manual was changed to add descriptions of the variables.	Resolved
20010	**Problem Description.** Volume I, Equation 3.5-314, DISSf on the lefthand side should be DISSg. **INL Notes.** The manual was updated appropriately.	Resolved
21010	**Problem Description.** The model has high temperature subcooled water flowing through various piping and component/fitting pressure drops, eventually falling below the saturation pressure and flashing, with two-phase choking occurring at the end of the line. Output files indicate most choking occurs in the junctions of pipe Volume 15 and in Junction 16 just downstream. Vol. 1 of the manual indicates: "Choking is defined as the condition wherein the mass flow rate becomes independent of the downstream conditions (that point at which further reduction in the downstream pressure does not change the mass flow rate)." The fundamental reason choking occurs is because acoustic signals can no longer propagate upstream. This occurs when fluid velocity equals or exceeds the propagation velocity. The choked-flow model is based on a definition established by characteristic analysis using time-dependent differential equations. A change downstream of where choking phenomena occurs will not affect the mass flow rate very much. Another user indicated that to match data better, discharge coefficients available for the choking model can be used. For example, if the pressure drop is 50% too small, discharge coefficients can be increased to a value of about 1.25 to better match the data. The subcooled/two-phase discharge coefficients should probably be different, but these factors should help increase flow rates. The user also mentioned that using the Henry-Fauske model may improve results by 5-10% but recommends starting with the discharge coefficients. **INL Notes.** One of the biggest observed issues is the choking occurring in the model due to flashing in the piping. This is a modeling issue that can be improved through input.	Resolved

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
21023	**Problem Description.** An Appendix K coding error was reported. Core power did not reduce correctly because the decay heat model did not turn on as expected. The code did not recognize a time when the decay heat model should be turned on. **INL Notes.** Appendix K coding did not recognize a time when decay heat coding should be activated. Coding was modified to activate when reactivity was less than -0.4. This resolved the observed issue.	Resolved
20001	**Problem Description.** If there is no volume feedback region defined, i.e., zero on W1 310000000, the code does not read the composition cards 32CCCXGN1. The code errors out reporting composition cards 32CCCXGN1 have not been read and compositions are missing. The problem seems to be that in rrkino.F, subroutine compdata which reads the 32CCCXGN1 cards, there is an if (if (rkn_nvr .gt. 0) then) that checks if there are volume feedback regions. This means if the input only has heat structure feedback regions (W1=0 and W2>0 on 310000000 (which is a valid input)) the cross sections are not read and no useful message is produced. Putting a 1 on W1 310000000 solves the problem. It should be required to have at least one volume and one heat structure feedback region. An even better solution is if in rrkino should check the volume and heat structure feedback regions, i.e., if ((rkn_nvr .gt. 0) .or. (rkn_nhr .gt. 0)) then. **INL Notes.** Recommend fixing the issue by testing that the number of volume regions PLUS the number of heat structure regions is greater than zero, to test and potentially implement change, i.e., if ((rkn_nvr + rkn_nsr) .gt. 0) then	In Progress
19005	**Problem Description.** The RELAP5 code has been using the reaction rate constant for oxide (as opposed to metal) to calculate metal destroyed and hydrogen generated. **INL Notes.** The reaction rate constant should be adjusted to be based on Zr-metal not Zr-oxide. Experiment data required	Future Release
200025	**Problem Description.** The gap conductance model fails if four compositions are used. This is necessary as some vendors put a coating on the surface of the fuel pellet. If three materials are used, the problem runs. **INL Notes.** Source coding currently does not support this option. Source code development required.	Future Release
200035	**Problem Description.** Depending on file name lengths (and more so directory names), the Strip output claims not to be able to read the plt input file (although it exists). It appears this is a more general problem with string variable lengths. The attached example shows how to reproduce the error varying the strip output file name, but similar behavior can be produced depending on the plt file name length. To reproduce the error, put the cond-2DRelap.i and Strip.i into a folder called Cond2DrelapStSt. From the parent directory of that folder, first run <path to relap executable> - i Cond2DrelapStSt/cond-2DRelap.i -p Cond2DrelapStSt/cond-2DRelap.plt this should create the cond-2DRelap.plt inside the folder Cond2DrelapStSt. Next, the following strip command completes without error and produces the csv <path to relap executable> - i Cond2DrelapStSt/Strip.i -O while the following fails with an error that the input plt file cannot be found: <path to relap executable> -i Cond2DrelapStSt/Strip.i -O Cond2DrelapStSt/Strip.o **INL Notes.** Modifications of string variable and array lengths Source code development required	Future Release

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
200055	**Problem Description.** On the 1CCCG501 card, Word 3, the 5xxx option (alternate heat structure fluid coupling), Appendix A states that the 5xxx option cannot be used with the 2D conduction model. Information Systems Laboratories (ISL) tried this combination, and it led to a numerical instability. Even though the manual says not to use this combination, the code did not generate an error message. It would be beneficial if the code generated a fatal error message in this case. **INL Notes.** Create error tracking and notification for this 5xxx option. Source code development required	**Future Release**
20007	**Problem Description.** An input file, which results in sodium boiling, fails without an abort when Option 37 is used. It also aborts with Option 55. The user was not worried about the abort, but it should give an error message before stopping. **INL Notes.** Create error tracking and notification for these Option 37 and 55 aborts. Source code development required	**Future Release**
20009	**Problem Description.** For 2D conduction, is appears the same boundary condition type is needed for all axial nodes on the left and right side of the heat structure. The only two boundary conditions (BCs) allowed are hydro volume or adiabatic (0). Any other BC leads to an input error. That check seems to work, i.e., the core correctly errors out if you try to use any other BC. All hydraulic volumes can be connected to the left side and adiabatic on the right side or hydraulic volumes everywhere (left and right). You can also have adiabatic on both sides left and right (used sometimes for problems that radiate to a surface and then conduct axially). If BCs are mixed (hydro volumes and adiabatic) on the left side, the input checker throws an error: 0 Reflood heat structure 1101001 must have the same boundary condition type for each of the Right/Left hand side. However, when BC is mixed on the right side of the heat structure (HS), input error is detected and the code crashes later. The manual says "each node of the HS needs to be connected to a hydraulic volume to make 2d conduction work." It does not say if that has to be on both sides or if the adiabatic BC can be used on one side (or both sides). It also does not say that each side of the HS has to use the same BC type. Maybe the manual can be clarified. As explained above, as long as the same BC is on all axial nodes of the HS (for each side), the problem runs with both sides adiabatic, both sides hydro connections or one side hydraulic volume and one side adiabatic. **INL Notes.** Create error tracking and notification for mixed boundary conditions on the right side of heat structure. Update relevant documentation. Source code development required	**Future Release**
21001	**Problem Description.** An error was discovered in the compressor model for a multi-stage compressor. The performance curves that were input into the first compressor (component 520) could not be referenced in the second and third compressors (components 521 and 522) without generating an input error. This referencing feature works with the pump component and the compressor coding was copied from the pump coding whenever possible. If the performance curves from the first compressor are copied into the second and third ones, the model runs. **INL Notes.** Create option to have performance curves input into the first compressor referenced by the second and third compressors. Update relevant documentation. Source code development required	**Future Release**

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
21002	**Problem Description.** A couple of code problems were encountered in the compressor model. The first was caused by a negative square root in the sound speed calculation for the compressor. The system was pure noncondensable and the working fluid was standard H20. A steam table call is not required in this instance, but a pressure enthalpy call is performed for generality in case working fluid is added during the transient. Historically, this error message is an indication of a problem with some of the properties or that the pressure/temperature grid used to generate the steam table is too coarse in this region. A simple fix was developed. A fatal error message is now generated only if the term inside the square root is negative and the noncondensable quality is less than 1.0. The error did not occur when fluid H2095 was used. **INL Notes.** Compare pressure enthalpy call for H20 and H2095 and determine if code problem is a result of experiment data range. Source code development required	Future Release
21003	**Problem Description.** An input deck fails if the user tries to use more than 100 points in the compressor speed table. The input manual indicates the speed table is limited to 100 pairs, which is consistent with the pump. So technically, this is not an error, but a potential code enhancement. Enhancements should have a lower priority than outright errors. **INL Notes.** Expand compressor speed table to 200 pairs. Source code development required	Future Release
21004	**Problem Description.** The code cannot read all upper-case input. When the 100 card is entered in uppercase format (shown below), the code gives an error statement indicating that the code is unable to determine processing type. 0000100 NEW TRANSNT If the input is changed to lowercase format, the code can read the input line. It is unknown how prevalent this issue is, but the input manual indicates that some input should be entered in uppercase, but some sections of the coding will not work with uppercase. **INL Notes.** Review coding to eliminate upper case character input. Update relevant documentation. Source code development required	Future Release
21005	**Problem Description.** In the original coding the density in the third term (1/ρ) is represented by variable prop(v_), which is the specific volume of the working fluid based on a pressure enthalpy call. This coding gives the correct answer when the compressor contains pure working fluid. However, if the compressor contains noncondensable gas with no working fluid, the code sets the partial pressure of the working fluid to 1.0 Pa, which leads to a huge specific volume when the working fluid in the system is H20. The correct density to use in this case is variable rhogt, which represents the stagnation density of the gas mixture, and is appropriate for pure working fluid, pure noncondensable, and mixtures of the two. The density of the noncondensable gas is about five orders of magnitude greater the density of the steam for the case being analyzed. **INL Notes.** Research partial pressure of noncondensable gas with no working fluid in the compressor. Update the working fluid density as appropriate. Source code development required	Future Release

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
21006	**Problem Description.** An additional code update should be made to the compressor coding. About 10 lines above the change to pslope in cprssr.F, there is the following debug printout. vlm(mkk)%extv53 = 1.0/prop(v_) It should be changed to vlm(mkk)%extv53 = rhogt This change is for completeness only and does not affect results. **INL Notes.** Confirm accuracy of using rhogt; that the verification test suite passes. Update relevant documentation. Source code development required	Future Release
21007	**Problem Description.** A user submitted a problem in which a restarted input deck fails shortly in a transient when a pump stop trip becomes true. This trip was first set in the base case and reset in the transient case. When the pump stop value changes to true at 2.0 seconds, its value becomes corrupted, and the case fails. The failing trip is number 498 and pump 897 is the pump that fails. **INL Notes.** Examine coding for pump stop value corruption in restart input deck. Determine necessary coding fix. Implement coding fix. Run verification test suite. Update relevant documentation. Source code development required	Future Release
21008	**Problem Description.** A successfully running deck fails after adding the magnetohydrodynamics card (Card CCC0003 for pipe component). This option has not been tested recently, and the cause of the failure is unknown. **INL Notes.** Examine coding for MHD card input. Update relevant documentation. Source code development required	Future Release
21009	**Problem Description.** A problem occurred in long-term loss of power calculations that support probabilistic risk assessment (PRA) analysis for the LWRS program. Many, but not all, failures could be fixed with time step reductions. The other failures could be fixed by replacing the jetpump with a branch on restart just before the failure, which occurred about 7 hours after the loss of power. By this time the recirculation pumps had coasted down, the jet pumps weren't pumping, and the system was near core damage. The workaround did not affect the long-term results other than limiting the code error. The first deck is the steady state model. The second deck is a transient restart that starts from the end of the steady-state run. It fails around 26000 seconds due to a jetpump problem. The third input deck is the work around that replaces the jetpump with a branch. The third problem runs, but the code failure with the second deck is what should be worked on. **INL Notes.** Examine coding for jetpump and transient restart. Determine coding modification. Update relevant documentation. Source code development required	Future Release
21011	**Problem Description.** A condensation heat transfer problem in which initially a pipe contains dry noncondensables with a noncondensable quality (quala) greater than 0.999 shows a discontinuity. When the noncondensable quality drops below 0.999 there is a discontinuity in the calculated heat transfer coefficient. When quala is greater than 0.999 the heat transfer coefficient is calculated using the Dittus-Boelter correlation, then when the quality drops below this threshold, the condensation subroutine is used for this calculation. There is an abrupt change in heat transfer correlation at this point. **INL Notes.** Examine coding for heat transfer correlation calculation in the presence of noncondensables. Determine coding modification. Update relevant documentation. Source code development required	Future Release

USER PROBLEM NUMBER	DESCRIPTION AND NOTES	INL STATUS
21012	**Problem Description.** A DGM test case fails in input 30 repeats on adv 31, no reason given by RELAP5-3D pre451j in the output file. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21013	**Problem Description.** A DGM test case fails at 11.39 s, 33 repeats, adv 5732, no reason given by RELAP5-3D pre451j in the output file. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21014	**Problem Description.** A DGM test case fails at 2.0 s with 601 repeats on adv 2761, no reason given by RELAP5-3D pre451j in the output file. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21015	**Problem Description.** A DGM test case fails at 10 s with 3 repeats on adv 13 for a liquid thermodynamic (TH) property error using RELAP5-3d pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21016	**Problem Description.** A DGM test case fails at 61.21 s with 21 repeats on adv 6153 for a liquid TH property error using RELAP5-3d pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21017	**Problem Description.** Test Cases 42-125 of a DGM test set have virtually no differences in the verification-files. The only difference is the hexadecimal for the Cntrl entry of the verification file. The decimal is identical. When that hexadecimal value is deleted, there are no differences. For RELAP5-3D pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21018	**Problem Description.** Cases 2, 5, and 6 of a DGM Test suite model fail verification backup testing. The differences occur in the 9th or 10th significant digit of P, Uf, Ug, VOIDg, QUALa, Vf, Vg, and Cntrl. For RELAP5-3D pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21019	**Problem Description.** Case 005 of a DGM test set fails verification backup testing. P, Uf, Ug, VOIDg, and QUALa differ in the 14th through 17th significant digit, Cntrl differs in the 12th place. For RELAP5-3D pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21020	**Problem Description.** Cases 29-32, 34-35, 37-40 of a DGM test set fail verification backup testing. Variables P, Uf, Ug, VOIDg, and QUALa differ in the 10th through 13th significant digit, Cntrl differs in the 11th place. For RELAP5-3D pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21021	**Problem Description.** Cases of 5, 7-9, 11, 12, 14, 16, 22, 28, 53, 55, and 58-60 of a DGM test set fail verification backup testing. P, Uf, Ug, VOIDg, QUALa, and Cntrl differ by varying amounts. For RELAP5-3D pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release
21022	**Problem Description.** Cases of 1, 5, 9, 13, 17 of a DGM test set fail verification backup testing. P, Uf, Ug, VOIDg, QUALa, and Cntrl differ by varying amounts. For RELAP5-3D pre451j. **INL Notes.** Will be resolved during DGM integration	Next Code Release

Summary of 2021 IRUG

INL virtually hosted the International RELAP5 User Group RELAP5-3D training and IRUG seminar on September 13-17, 2021.

TRAINING

The RELAP5-3D training was organized on September 13-15, 2021. A total of 43 people attended the training, comprised of two three-day courses run simultaneously: beginner training and advanced training.

The basic level training program included:

- Overview of the RELAP5-3D code
- Introductions to RELAP5-3D fluid dynamics and heat transfer theories
- Detailed descriptions of the input for modeling hydrodynamic components, heat structures, trips, and controls
- Explanations of the output file
- Exercises on code usage and input creation.

The advanced level program covered higher level engineering concepts with assessment practices including:

- Fluid properties
- Pump modeling
- Steady state problem exercises.

An optional test was provided at the end of each course and a certificate awarded to those who passed.

SEMINAR

The IRUG seminar was held on September 16 and 14 technical presentations were given by RELAP5 users at four sessions:

- RELAP5-3D code and capabilities
- Uncertainty and testing
- Assessment
- Modeling.

Session one included presentations on code development and maintenance:

- Remote RELAP5-3D
- GNU Fortran version
- Status on user problems and new version release schedule.

Session two included presentations on uncertainty and testing:

- Best-estimate plus uncertainty method application with RELAP5-3D
- Regression testing for BR2 model and uncertainty scaling effect.

Session three included presentations on assessment:

- Analysis result from hydraulic loads
- Human reliability
- Accident tolerant fuel.

Session four included technical presentations on modeling:

- Japanese high temperature test reactor
- U.S. micro-reactor experimental facility MARVEL
- Plutonium fuel experiment
- High-energy deposition transient test.

BUSINESS MEETING

The business meeting was organized on September 17, 2021. Board members of IRUG were elected: Yong-Joon Choi (president), Nolan Anderson (vice-president) and Mauricio Tano (secretary). A discussion session was held to collect feedback on the training. Most issues were due to the on-line training format. Business topics were addressed by Theron Marshall (business manager) including the new licensing fee structure, export control concerns, and a plan for leveraging remote RELAP5-3D. The next version of the RELAP5-3D release plan was presented by Nolan Anderson.

International RELAP5 User Group Meeting Idaho National Laboratory September 13 – 17, 2021

Idaho National Laboratory

International RELAP5 User Group Meeting

September 13-17, 2021

RELAP5-3D Training: Basic Level

09/13/2021	Introductions and Basic Hydrodynamics
09/14/2021	Heat/Mass Transfer and Heat Structures
09/15/2021	Other Hydrodynamic Components and Processes

RELAP5-3D Training: Advanced Level

09/13/2021	Introductions, Coding, and Pump Exercise
09/14/2021	Special Models and Enclosure Exercise
09/15/2021	Steady-State and Nodalization

RELAP5-3D Seminar

09/15/2021 – 09/17/2021

RELAP5-3D Business Meeting

09/17/2021

Host: Idaho National Laboratory

International RELAP5 User Group Meeting

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RELAP5-3D Stakeholders

Appendix A

2021 IRUG PRESENTATIONS

The 2021 IRUG meeting presentations can be found on the RELAP5-3D website.

PRESENTATION TITLE	PRESENTER
Remote RELAP5-3D Information	George L. Mesina
RELAP5-3D Architectural Upgrades through Gnu Fortran Adaptation	George L. Mesina
Development of Best Estimate Plus Uncertainty Application for RELAP5-3D	Yong-Joon Choi Carlo Parisi
Application of Surrogate Models for Best Estimate Plus Uncertainty Analysis by RELAP5 Code	Ikuo Kinoshita
Regression Testing for BR2 RELAP5 Models	Hsun-Chia Lin Patrick Garner Jeremy Licht Frank Wols
Modern Error Scaling	Aaron Epiney
Application of RELAP5-3D for Liquid Metal Reactor Safety	Fabio Giannetti
Human Reliability Analysis	Ron Boring
Risk-Informed ATF Analysis for Generic PWR and BWR	Hongbin Zhang
JAEA HTTR Secondary System Modeling	Nolan Anderson
Thermal-Hydraulic Modeling of MARVEL Microreactor	Carlo Parisi
Overview of the Plutonium Fuel Services Irradiation Experiment in the Advanced Test Reactor	Joshua Fishler
Application of RELAP5-3D to High Energy Deposition Transients within TREAT	Cole Blakely

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