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Validation of the G-PASS Code: Status Report

Nuclear Engineering Division

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Validation of the G-PASS Code: Status Report

by

R.B. Vilim
Nuclear Engineering Division, Argonne National Laboratory

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VALIDATION OF THE G-PASS CODE: STATUS REPORT

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ABSTRACT

Validation is the process of determining whether the models in a computer code can describe the important phenomena in applications of interest. This report describes past work and proposed future work for validating the Gas Plant Analyzer and System Simulator (G-PASS) code. The G-PASS code was developed for simulating gas reactor and chemical plant system behavior during operational transients and upset events. Results are presented comparing code properties, individual component models, and integrated system behavior against results from four other computer codes. Also identified are two experiment facilities nearing completion that will provide additional data for individual component and integrated system model validation. The main goal of the validation exercise is to ready a version of G-PASS for use as a tool in evaluating vendor designs and providing guidance to vendors on design directions in nuclear-hydrogen applications.

I. INTRODUCTION

Validation is the process of determining whether the models in a computer code can describe the important phenomena in applications of interest. This report describes past work and proposed future work for validating the Gas Plant Analyzer and System Simulator (G-PASS) code. [1] The G-PASS code was developed to simulate gas reactor and chemical plant system behavior during operational transients and upset events.

The G-PASS code is ideally suited as a tool for use in nuclear-hydrogen plant design and control system studies. Typically a large number of simulations are needed to identify those design tradeoffs that best meet objectives. One must choose from among many permutations of equipment configurations and plant operating conditions. Simulation run times can, however, be long and so a means for facilitating rapid simulation of a large numbers of cases is desirable. The G-PASS code approaches this problem in two ways. First setting up a simulation problem with G-PASS typically can be done without having to modify source code. Second the user can limit model detail to a level appropriate to the problem. As a consequence the resulting code is less complex than a large systems code while typically containing more detailed phenomenology than commonly found in spreadsheet applications.

The objective of this report is to identify the current status of work on comparing the code results with experiment and other codes. The work on G-PASS validation to date is presented and additional validation work that is needed is identified. The goal is to present a plan for code validation should G-PASS have a role to play as a tool for evaluating vendor designs or providing guidance to vendors on design directions for nuclear-hydrogen applications. This report is limited to validation of models for simulation of the Next Generation Nuclear Plant (NGNP) coupled to the High Temperature Electrolysis (HTE) process.

II. VALIDATION

The objective is to establish that the code when used to predict plant response for the operational and upset envelopes of interest can represent the important physical phenomena and yields with high confidence accurate predictions for these phenomena. Validation does not include verification which is the process of establishing that the code numerical methods correctly implement and solve the intended equations.

Validation involves comparison of code results with results from experiments and other computer codes for benchmark problems. These comparisons are carefully defined to get at the important physics. To capture both separate effects and integrated behavior a sequence of benchmarks is defined that address first individual phenomena taken in isolation and then the collective behavior of these phenomena in an integrated setting. In this work the sequence involves first examining properties, then constitutive equations that are dependent on these properties, then individual equipment or component studies, and finally the integrated behavior of the plant as composed of these individual components.

III. CODE DESCRIPTION

G-PASS is a gas reactor plant systems code intended for preliminary safety analysis and for evaluating plant control strategies. The code makes use of component modules and a general equation solver to provide the user with a flexible capability for configuring plant components. Basic components provided include a point kinetics core, turbine, compressor, single phase and two-phase heat exchangers, bypass valve, accumulator, containment, and flow split and flow merge junctions. These components and the capability to configure them in different arrangements facilitates the study of safety and operational consequences of direct versus indirect plant layouts, parallel versus series heat load layout, and size and speed of operation of actuators such as bypass valve. Typically, compared to a large systems code such as RELAP [2], the code permits more rapid assessment of plant design concepts. The code solves the dynamic mass and energy equations for each component and the quasi-static coolant momentum equation for the flow network. The user can select which variables are to be used as boundary conditions in the steady state and as forcing functions in a transient. A quasi-static solution mode is available for design of the plant load schedule.

Major Features:

A. A network of components configured using flow junctions can be solved. Network is user inputable without need to reprogram source code.
B. Isentropic efficiency with real properties rather than polytropic efficiency is used to model turbomachines.
C. Heat exchanger model with multiple axial nodes and flow dependent heat transfer and pressure drop.
D. Constraint-based quasi-static solution mode for plant load schedule design.
E. PID controller module.

Major Assumptions:

A. Quasi-static lumped parameter representation for momentum conservation in each component. i.e. the inertial term is neglected.
B. Reactor point kinetics equations across a time step are solved outside of the rest of the system.

Turbo-machine Performance Curves:
A generic capability exists for entering performance curves as tables of enthalpy rise, pressure rise, and efficiency as independent functions of speed and mass flowrate. Off-design inlet temperature is corrected for through an ideal gas treatment. A default set of non-dimensional performance curves is provided.

Equation of State Model for the Coolant: Gas coolant thermophysical properties are from NIST [3]. Property values can be obtained either by direct evaluation of the NIST polynomials or by interpolation of precomputed tables generated from the NIST polynomials.

Solver: Fully implicit time-differenced simultaneous solution of all component models prescribed through the user input (with the exception of reactor kinetics and control system models). Equations are solved using a modified Powell hybrid algorithm and a finite-difference approximation to the Jacobian. Multi-node heat exchanger model is solved in an inner iteration loop. The Kaganove-Fuller technique for stiff equations is used to solve the reactor kinetics equations. The coupling of reactor kinetics and the control system to the rest of the code is explicit.

Time Step Control: Variable time step control driven by required solution accuracy. User imputable table of time step size expressed as a function of time into transient simulation.

Integrated System Simulations to Date:

A. Gas reactor in closed helium Brayton Cycle. Direct cycle coupling. Investigation of reactor inherent response during unprotected loss of load.[4]
B. Gas reactor, closed helium Brayton Cycle, and low temperature thermochemical process for electricity and hydrogen production. Investigation of coupled plant cycle efficiency and temperature variation over load schedule.[5]
C. Gas reactor in closed supercritical carbon dioxide Brayton Cycle. Indirect cycle coupling. Investigation of control strategies for Power Conversion Unit.[6]
D. Indirect cycle closed helium Brayton Cycle with High Temperature Electrolysis plant. Investigation of control strategies for minimizing temperature change in IHX during duty-cycle transients.[7]

Platforms and Language: Windows and Unix-based Fortran 90

IV. PROPERTIES

Fluid properties in GAS-PASS are obtained from the NIST RefProp code.[3] The NIST RefProp code can calculate a variety of fluid properties for numerous fluids. As for the accuracy of estimates the following item appears in the RefProp documentation:

> REFPROP is based on the most accurate pure fluid and mixture models currently available. It implements three models for the thermodynamic properties of pure fluids: equations of state explicit in Helmholtz energy, the modified Benedict-Webb-Rubin equation of state, and an extended corresponding states (ECS) model. Mixture calculations employ a model which applies mixing rules to the Helmholtz energy of the mixture components; it uses a departure function to account for the departure from ideal mixing. Viscosity and thermal conductivity are modeled with either fluid-specific correlations or an ECS method.

RefProp provides the ability to calculate numerous different fluid properties. It allows the user to input various properties to get the desired value e.g. one may use enthalpy and entropy to calculate temperature. RefProp accomplishes this with an equation of state in temperature and pressure by performing numerical convergence iterations when properties other than temperature and pressure values are entered. RefProp 7.0 provides properties for 52 different fluids.

A study of the differences in property values obtained amongst the three equations of state models is described in [8]. Due to the relatively small differences between model values and the limited temperature range of the BWR model (to only 440.1 K while the FEQ model goes to 1100 K, a realistic temperature for possible applications), the NIST default model FEQ is used in G-PASS.

The benefits of the NIST RefProp code come at the cost of considerable complexity and therefore slow runtime. The solution adopted [8] is to pre-compute fluid property data and store it in tabular form. The user can still have the flexibility to create tabular data for any fluid or fluid mixture and can create tables with any input or output properties. Tables offer the advantage of unrestricted distribution, whereas NIST RefProp is a commercial code.

A. To Date

The enthalpy and entropy data in G-PASS [tables derived from NIST polynomials] for helium, oxygen, and nitrogen have been compared against data in [9] as a function of temperature and pressure. The results appear in Figures 1 through 6. The errors are generally less than two percent with the maximum deviation reaching six percent.

B. Proposed

The FEQ model properties for hydrogen in RefProp have an upper temperature limit of 127 C (400 K). But for hydrogen production applications an upper limit of at least 1000 C is required. This low upper temperature limit has been identified by RefProp developers as a deficiency and item for future improvement. [10]

Presently G-PASS uses data in [9] for the properties of hydrogen. A proposed task is to locate a second source of hydrogen property data against which to compare the current G-PASS properties.

In addition to enthalpy and entropy property data benchmarked above for oxygen, nitrogen, and helium, these same gases plus hydrogen need to be compared against other data for viscosity, thermal conductivity, and density. These three properties appear in constitutive equations for friction pressure drop and heat transfer flux in G-PASS.

V. CONSTITUTIVE EQUATIONS

The heat transfer and pressure drop correlations used in G-PASS have their basis in the work of [11] and [12]. In those references the literature is reviewed and correlations for gas reactors recommended. The correlations in G-PASS are based on those recommendations. The description below of the correlations is adopted from [8].

A. Heat Transfer

The Gnielinski correlation [13] for turbulent flow in a tube with entrance length correction is used.

For laminar fluid flow Hesselgreaves' recommendations [14] are followed, including interpolating tabular data for the entrance length effects.

A transition region is used to create a smooth change from laminar to turbulent correlations. Since the turbulent correlation begins at 2300, a transition region was chosen to range from 500 above and below the transition point i.e. 1800 < Re < 2800. This region uses linear interpolation to create a smooth transition between the laminar and turbulent Nusselt numbers to calculate the heat transfer coefficient.

See [8] for a pseudo-code description of the heat transfer coefficient calculation procedure.

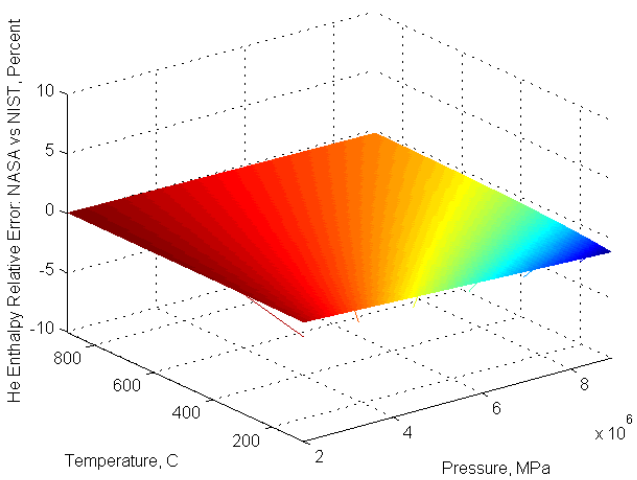

Figure 1 Enthalpy of Helium – NASA Data Relative to NIST

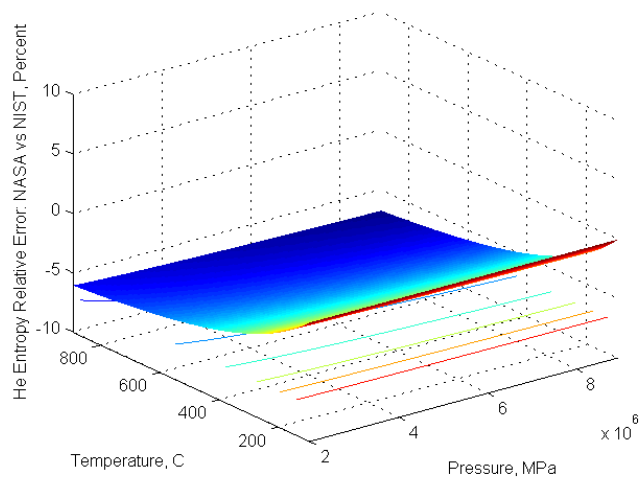

Figure 2 Entropy of Helium – NASA Data Relative to NIST

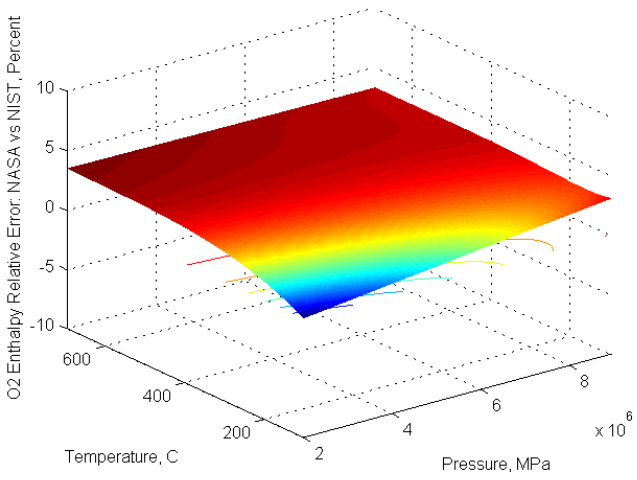

Figure 3 Enthalpy of Oxygen – NASA Data Relative to NIST

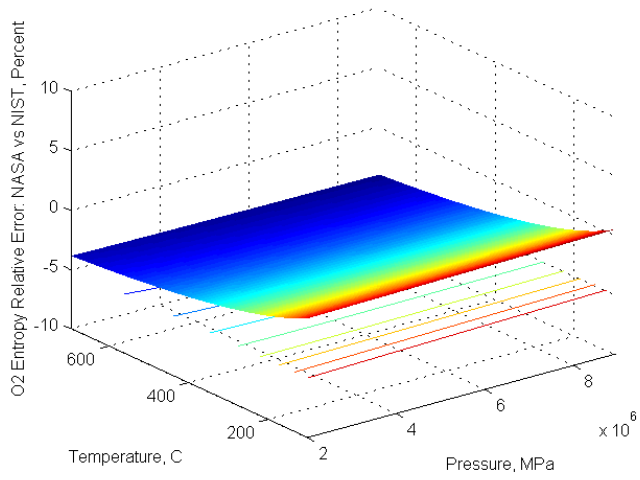

Figure 4 Entropy of Oxygen – NASA Data Relative to NIST

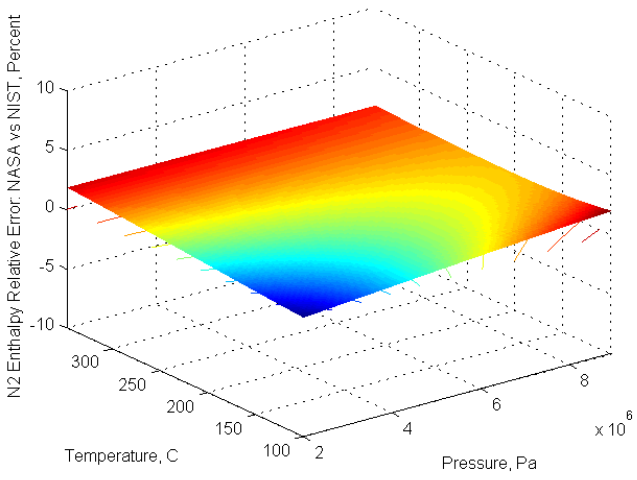

Figure 5 Enthalpy of Nitrogen – NASA Data Relative to NIST

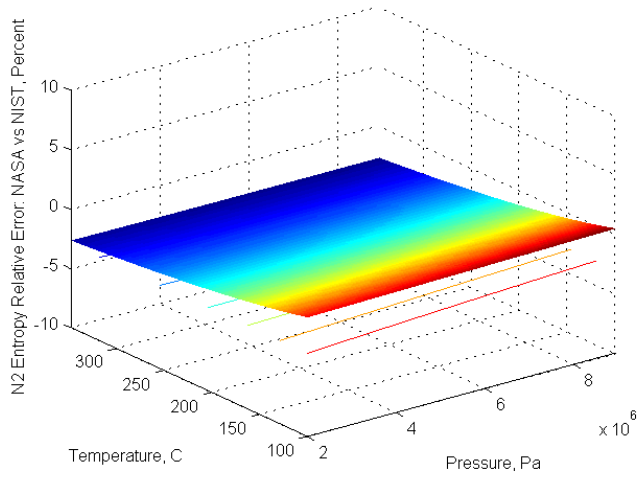

Figure 6 Entropy of Nitrogen – NASA Data Relative to NIST

B. Pressure Loss

The method for calculating pressure drop is taken directly from code originally created by Hejzlar and used by Dostal [15]. The approach is based upon Idelchik. [16]

The pressure loss is calculated as a function of Reynolds Number and tube smoothness. The Reynolds Number flow transition points depend upon tube smoothness. The relative smoothness is the ratio of deviation peak size to tube diameter:

$$\delta_{rel} = \frac{\delta}{D}$$

See [8] for a pseudo-code description of the pressure loss calculation procedure.

C. Proposed

Inspection of the above heat transfer and pressure loss methods reveals a network of coding logic tests based on Reynolds number and pipe smoothness. The complexity of this network rules out a simple point test for the validity of the implemented models. Perhaps the simplest tests for validity are of an integral nature as proposed in Sections VI.C and VII.B below.

VI. COMPONENT MODELS

If a systems code is to produce accurate and reliable predictions for plant behavior, then a pre-requisite is that individual component models be valid. In this section past and planned validation work for individual components is described.

A. Turbo-Machines

The method in G-PASS for modeling a turbine or compressor is described in [17]. Essentially, output conditions are linked to input conditions through performance maps. These maps give efficiency, pressure rise, and enthalpy rise as a function of mass flow rate and shaft speed. The performance maps themselves are essentially fitted data obtained by solving the conservation equations for the component while adopting phenomenological models for various loss terms. [18]

The default performance maps in G-PASS are shown in Figures 7 through 10. These maps exhibit the main features of how efficiency and enthalpy rise trend with shaft speed and mass flow rate in a near ideal gas machine. They were obtained by fitting polynomials to performance curve data for a helium compressor and turbine after using relatively simple theory to non-dimensionalize the data and to express it in terms of mass flow rate to speed ratio. Their use should be limited to generic studies of plant response since the fitting process involved making significant approximations.

In the G-PASS method for modeling a turbo-machine, validation would amount to 1) confirming that the predicted model outputs are consistent with the performance map data and 2) that the performance maps themselves are valid.

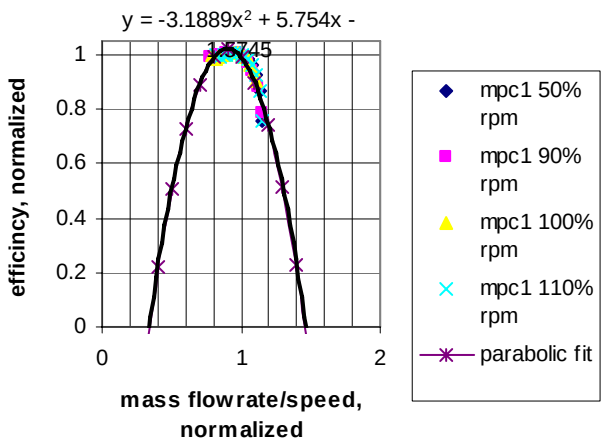

Figure 7 Generic Compressor Efficiency Performance Map

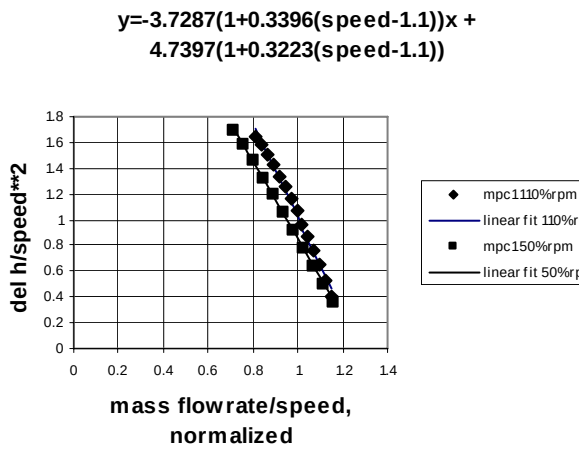

Figure 8 Generic Compressor Enthalpy Rise Performance Map

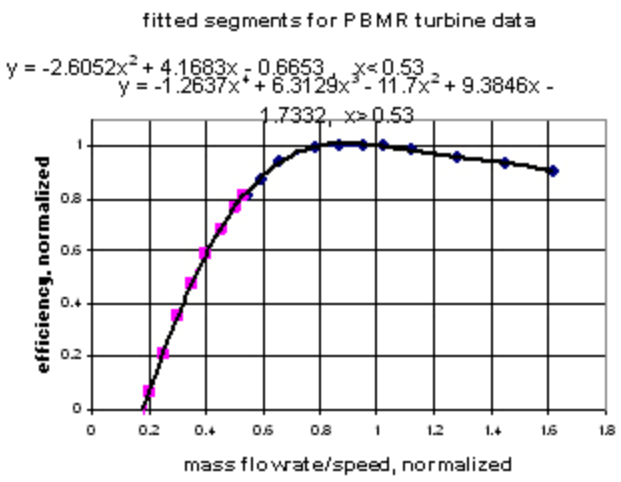

Figure 9 Generic Turbine Efficiency Performance Map

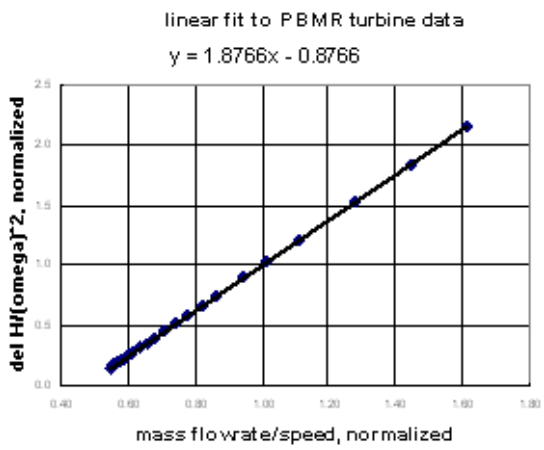

Figure 10 Generic Turbine Enthalpy Rise Performance Map

Turbo-machine validation in G-PASS makes sense only in the context of a specific set of performance curves for a specific turbo-machine design. Such data does not exist for the NGNP at this time. Until such time as specific data exists, it is premature to consider validation.

B. Electrolyzer

The electrolyzer model has been compared against steady-state data and against transient data. The results are presented below.

In the steady-state case, the comparison is against results from two different models described in.[19] The first model is a three-dimensional representation of the cell that uses the computational fluid dynamics code FLUENT. The second model is a one-dimensional representation with space discretization. The cell model in G-PASS is by comparison a simpler model that assumes a single spatial node with perfect mixing for species concentration and stream temperature. The three models were compared for a set of fixed inlet conditions at atmospheric pressure with current density as an independent variable. The cathode inlet stream was 0.0625, 0.568, and 0.370 mole fractions H_2, H_2O, and N_2, respectively, and the anode inlet stream 0.210 and 0.790 mole fractions O_2 and N_2, respectively. The cathode and anode stream mass flowrates were 8.00E-06 and 4.00E-06 kg/s, respectively. The area specific resistance (ASR) was 0.7 ohms-cm^2 and the electrolyte area 64 cm^2.

A comparison of results is shown in Figures 11 and 12. Figure 11 shows the cell operating voltage as a function of current density. The curve annotated with the square symbol is the G-PASS result and is seen to very nearly overlay the FLUENT curve. Figure 12 shows the cell outlet temperature as a function of cell operating voltage. The curve annotated with the diamond symbol is the G-PASS result. The curve trends the same as the FLUENT curve while the maximum difference between the two is about 20 C. This compares with about a 120 C variation of outlet temperature over the range of operation shown. It is concluded that the G-PASS model provides reasonable results, certainly good enough for scoping studies.

In the transient case, the cell time constant associated with the G-PASS electroyzer model is compared against a value deduced from an experiment described in the literature. This comparison provides confirmation of the validity of assumptions made in the derivation of the one-dimensional G-PASS model. The model ignores the two-dimensional nature of the temperature distributions in the electrodes, electrolyte, and gas streams that arise as a consequence of the planar rectangular geometry of the cell and the 90 degree difference in angle of incidence between the two gas streams. In addition the heat capacity of the steel separators and edge rails is neglected since their temperature state is thought to be not tightly thermally coupled to the electrodes and electrolyte.

In the experiment the identical Cerametec cell that is being used for water splitting SOEC studies at Idaho National Laboratory (INL) was run in fuel cell mode. The cell was operated at atmospheric pressure and hydrogen and oxygen were fed into rather than removed from the cell. The mole fractions of hydrogen, oxygen, and water estimated from [20] were 0.46, 0.2, and 0.85. The water-splitting model in G-PASS was modified to describe a fuel cell by a change of sign on the Nernst potential and the Gibbs standard free energy of formation (to account for interchange

of products and reactants). With these adjustments and for the conditions in [20] the G-PASS model yields a cell time constant of 279 s.

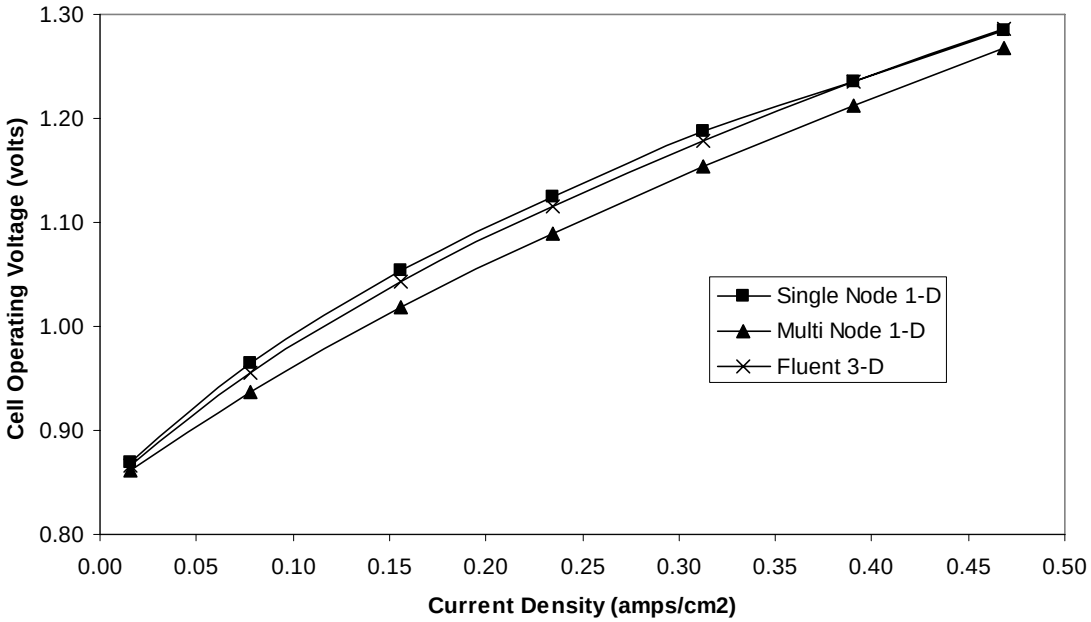

Figure 11 Comparison of Operating Voltage from Single Node 1-D Electrolytic Cell Model with More Detailed Models

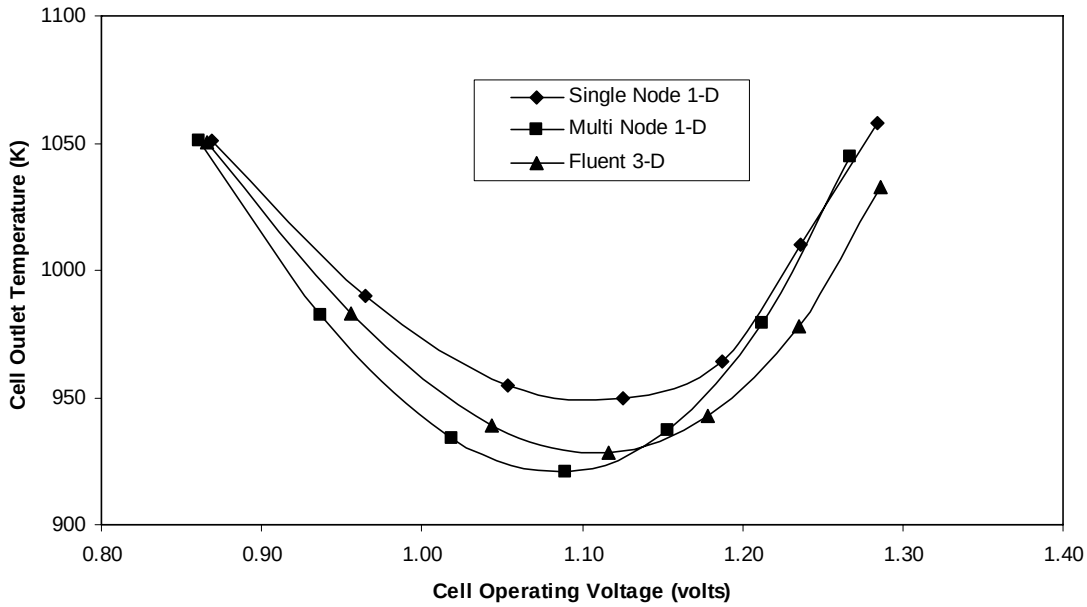

Figure 12 Comparison of Outlet Temperature from Single Node 1-D Electrolytic Cell Model with More Detailed Models

A value for the time constant of the cell was derived from data in [20]. In the experiment the fuel cell was at a steady state prior to a step change in the cell current. The measured cell outlet temperature during the subsequent transient appears in Figure 13. The description in [20] indicates there was an initial power supply problem and, hence, the appearance of a saw tooth on the ramp up in temperature. We have attempted to adjust for this by backward extrapolating in time after the occurrence of the sawtooth. Figure 13 shows the back calculation of a value for the time constant from the experiment data. The value of 279 s calculated from the G-PASS model differs by 19 percent from a value of 235 s obtained from the annotations added to Figure 13. This indicates that the G-PASS model is reasonable from the standpoint of estimating an approximate measure of cell outlet temperature time response.

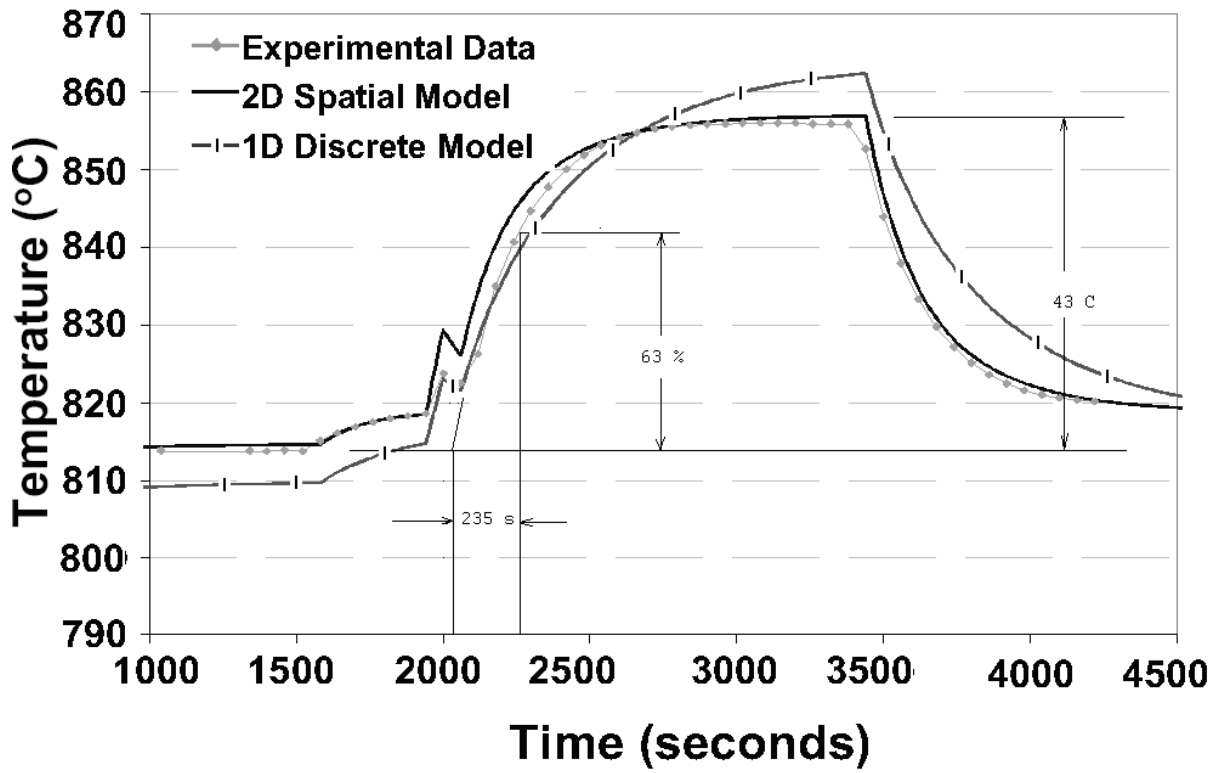

Figure 13 Time Constant for an Electrolytic Cell Operating in the Fuel Cell Mode

C. Heat Exchanger

The heat exchanger model in G-PASS has been benchmarked against other codes. The case described here is a comparison with results obtained from RELAP. This case is from [8].

In this comparison a Printed Circuit Heat Exchanger (PCHE) with super-critical carbon dioxide on the hot-side and water on the cold side is subjected to a step increase in hot-side inlet temperature. The transient simulation begins with steady state conditions from which point the hot fluid inlet temperature is linearly increased 40 C over 0.05 seconds -- a close approximation of a step change. This higher temperature is held for the rest of the simulation and the other fluid

inlet values were not changed. Both codes were run with the heat exchanger divided into ten equal-sized axial nodes.

The hot-side fluid undergoes significant density changes during this transient. Since the incoming mass flow rate is constant significant changes in mass flow rates for short periods of time are seen at the outlet. If the fluid density decreases (i.e. temperature rises) then the PCHE will reject fluid for a short amount of time, as shown in the large peak in Figure 14. This figure shows that both G-PASS and RELAP5 predict a significant spike in outlet mass flow rate

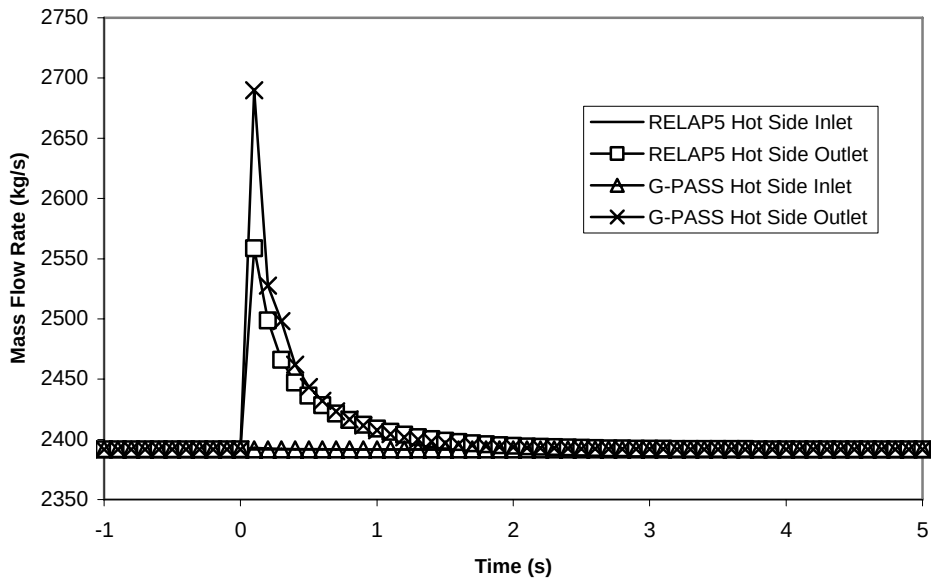

Figure 14 Comparison of RELAP and G-PASS Heat Exchanger Outlet Mass Flow Rate Response: Hot Side Inlet Temperature Step Increase

However, G-PASS predicts a larger spike than RELAP5 does. The difference is attributed to what in RELAP5 is a proper treatment of the momentum equation while G-PASS uses a quasi-static momentum conservation equation. As a consequence, RELAP5 shows the effect of fluid inertia while G-PASS does not. Therefore the RELAP5 spike will be smaller and slower, both of which are clearly seen. G-PASS performance is considered acceptable because expected transients will be much slower than the case shown here.

The corresponding transient outlet temperature are shown in Figure 15.

The steady state outlet temperature values and heat transfer are compared in Table I. The relative errors are well within the expected heat transfer correlation uncertainties. Note that a key area of uncertainty in heat transfer stems from the laminar to turbulent transition on the water side.

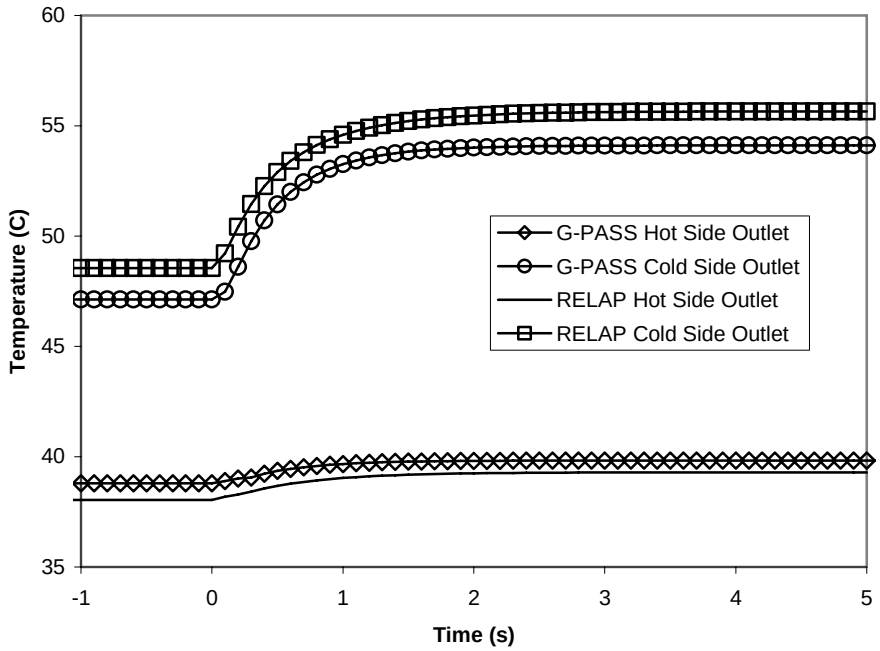

Figure 15 Comparison of RELAP and G-PASS Heat Exchanger Outlet Temperature Response: Hot Side Inlet Temperature Step Increase

Table I Comparison of RELAP and G-PASS Heat Exchanger Steady-State Outlet Temperature

	RELAP5	G-PASS	Discrepancy
Hot-Side Outlet Temp (°C)	37.90	38.85	+0.95°C
Cold-Side Outlet Temp (°C)	48.40	47.05	-1.35°C
Heat Transfer Rate (MW)	425.9	402.2	-5.6%

The highly similar time dependent behavior and the relatively small error between heat transfer predictions shown between G-PASS and RELAP5 suggest that G-PASS is sufficiently accurate for scoping design studies. As more accurate heat transfer correlations become available and are incorporated, this assertion should be revisited.

D. Planned

The Small-Scale Test Facility under construction at Sandia National Laboratory (SNL) [21] will generate data that can be used to validate turbo-machinery models in the G-PASS code. This facility will host experiments for individual components (compressor and turbine) and for integrated experiments (turbine bypass operation and flow-split compressor operation). While the coolant will be carbon dioxide rather than helium, the loss mechanisms in individual components and the equipment configuration in system operation have their NGNP helium counterparts. Work is already underway to validate the radial compressor model in G-PASS. [17]

VII. INTEGRATED SYSTEM MODEL

A. To Date

The G-PASS code predictions for a load change transient were compared against results obtained from the Plant Systems Dynamics Code. [22] The comparison was performed for a closed-loop Brayton cycle with super critical carbon dioxide as the working fluid. The heat rejection step of the cycle operates very close to the critical point of carbon dioxide (31.0 C / 7.4 MPa). The configuration of components is shown in Figure 16. In this plant the turbomachines operate on a single shaft reducing the equipment count from what it would be otherwise. A pinch point associated with the large change in specific heat of carbon dioxide near the critical point occurs when a single recuperator is used. To better match specific heats on the cold and hot side and thereby increase cycle efficiency, two compressors and two recuperators are used as shown in Figure 16. The layout in this study is an indirect cycle meaning that an intermediate heat exchanger couples the cycle to the reactor primary loop.

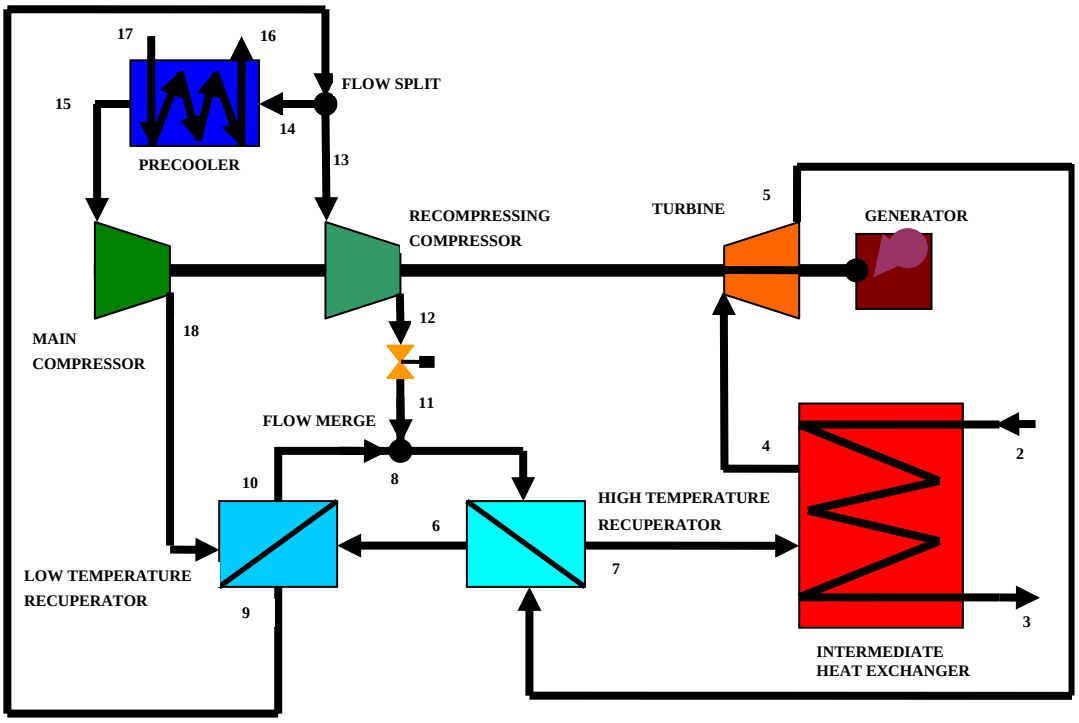

Figure 16 Indirect S-CO2 Recompressing Cycle

The Plant Systems Dynamics Code solves time-dependent equation of a *real gas* compressible flow dynamics. The exact CO_2 properties are calculated at every time step at many nodes throughout the cycle. For example, the CO_2 properties are calculated at several axial locations along each heat exchanger; thus, accounting for the dependence of the heat transfer on the CO_2 properties (both pressure and temperature). The turbomachinery (TM) parameters are calculated each time step based on the performance maps. The performance maps are calculated based on

the exact CO_2 properties at TM boundaries (inlet temperature and pressure, outlet pressure, and rotational speed) as well as CO_2 properties variation along the TM stages; no ideal gas assumptions are made anywhere in the code.

The two codes were used to simulate a 10% step change in the output of the electric generator assumed to arise from a change in the electric grid demand for power. Both codes use the same control system for regulating generator output: turbine bypass.

There were some differences between the cases each code simulated. The details can be found in [22]. Briefly, while both codes simulated the same plant configuration, reactor power and reactor outlet temperature differed between the two cases. This was adjusted for in the comparison by normalizing variables to full power conditions.

Both codes were run in a manner that provided for the same condition at the hot inlet to the cycle. Specifically the transients were run for constant turbine inlet (i.e. IHX cold side outlet) temperature. This was achieved essentially by manipulating conditions in the primary system. This had the effect of removing reactor behavior from the simulation.

The transient resulting from a step change in generator output setpoint was simulated with each code. Variables prescribed as a function of time were: the cooler cold side water inlet temperature was fixed and the turbine inlet temperature was maintained essentially constant. In the GAS-PASS code the turbine inlet temperature is maintained constant via the turbine inlet temperature controller. In the Plant Dynamics Systems code a different approach resulted in essentially constant turbine inlet temperature. Both codes used turbine bypass control to meet the change in electric power demand.

The results of the simulations are shown in Figures 17 through 26. The GAS-PASS/CO2 results appear on the left-hand side of each figure and the Plant Dynamics Systems code results on the right-hand side.

The agreement between code results is qualitatively quite good considering the plant sizes differ by more than a factor of ten. The trend in time of variables between codes is in good agreement. There is some difference between plants in the rate at which processes equilibrate. But given that there was no explicit relationship linking component sizes between the two plants and that that there was no attempt to use the same values for controller integral constants, this is to be expected.

It is concluded from Figures 17 through 26 that both codes with their respective plant give comparable results.

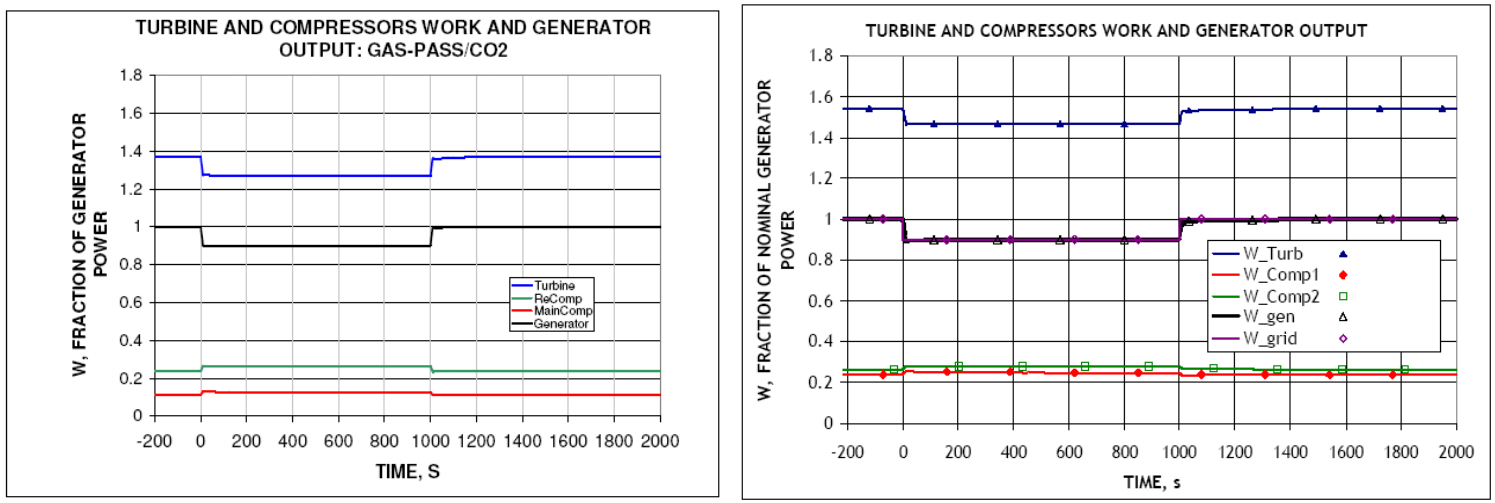

Figure 17 Step 10% Load Change Transient: Turbomachine Work

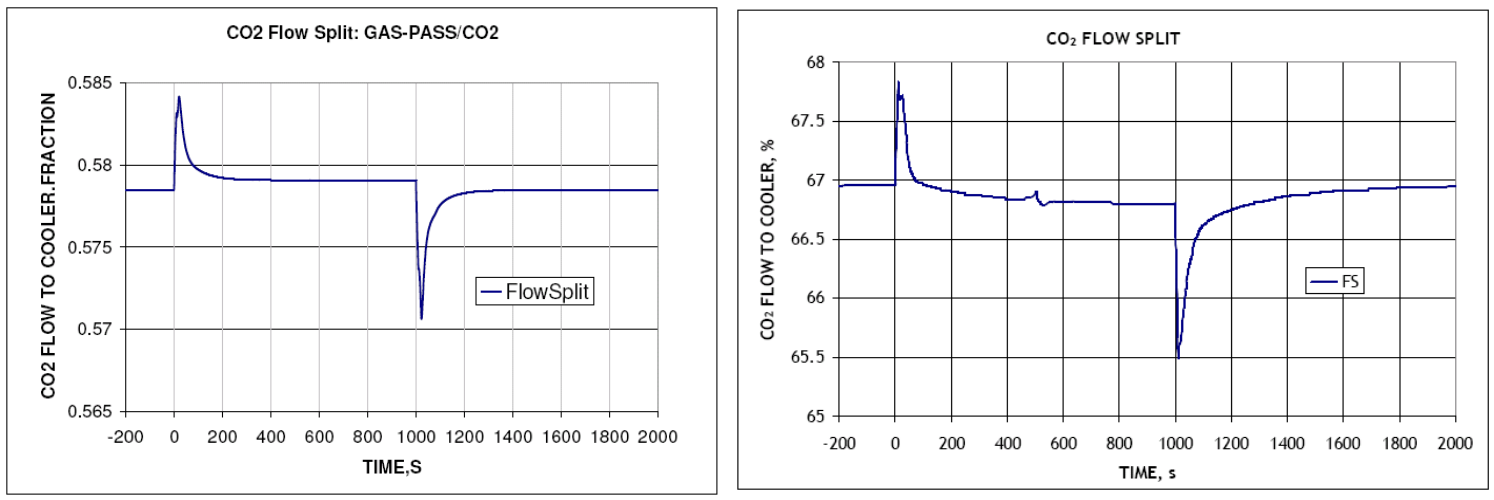

Figure 18 Step 10% Load Change Transient: Flow Split to Cooler

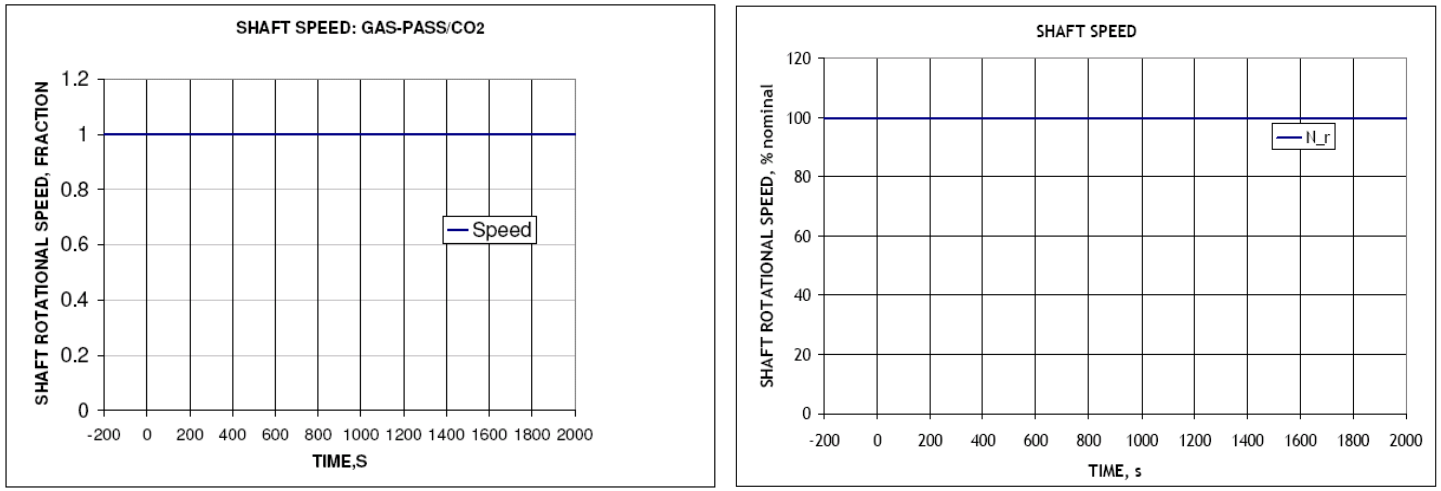

Figure 19 Step 10% Load Change Transient: Shaft Speed

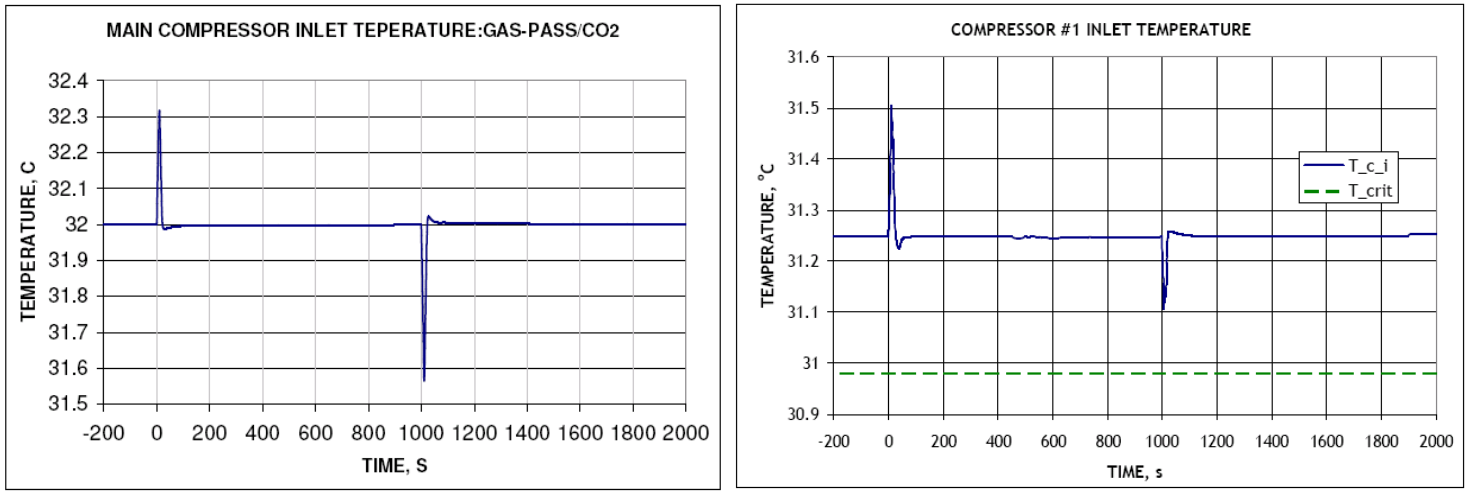

Figure 20 Step 10% Load Change Transient: Main Compressor Inlet Temperature

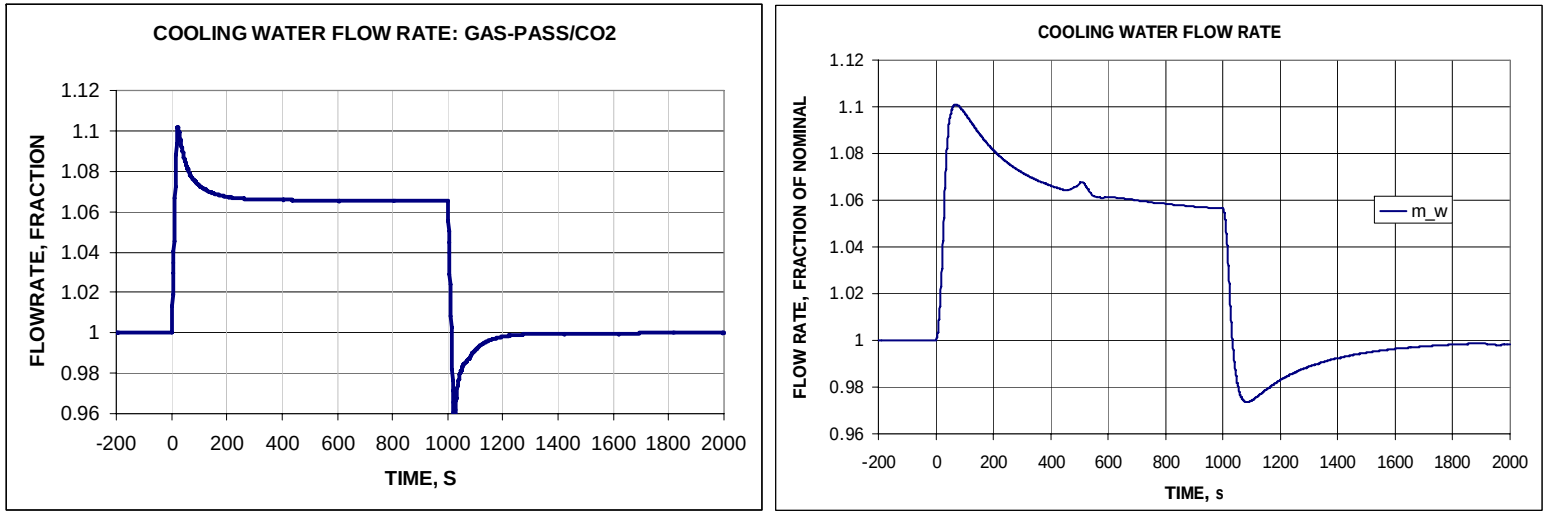

Figure 21 Step 10% Load Change Transient: Cooling Water Mass Flow Rate

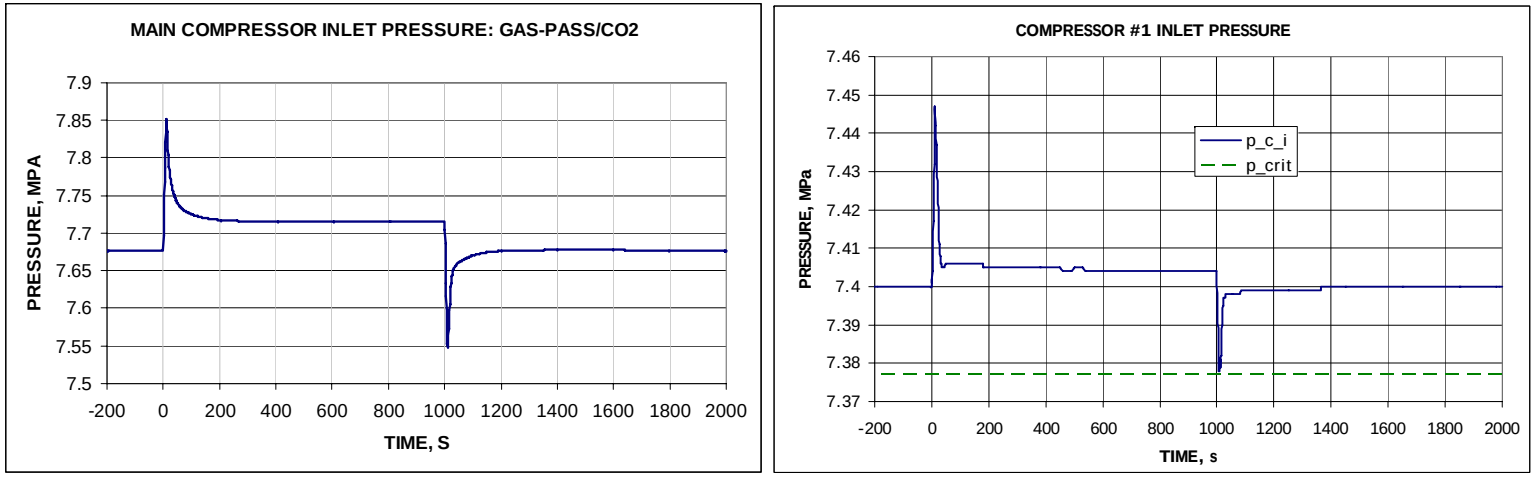

Figure 22 Step 10% Load Change Transient: Main Compressor Inlet Pressure

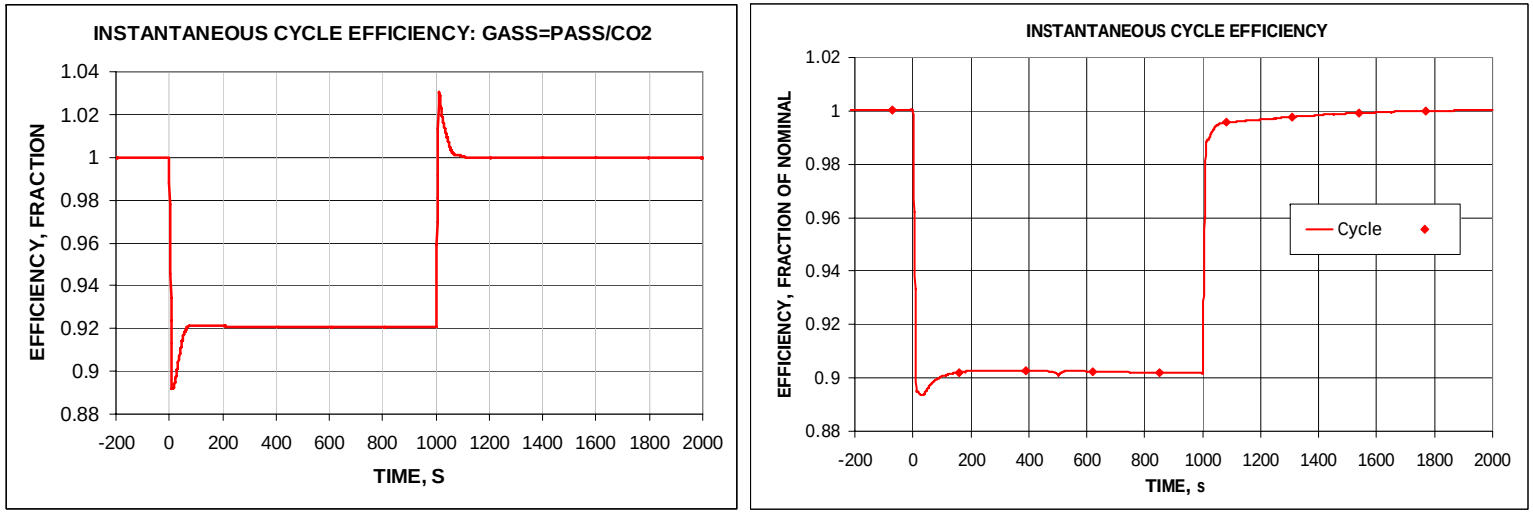

Figure 23 Step 10% Load Change Transient: Instantaneous Cycle Efficiency

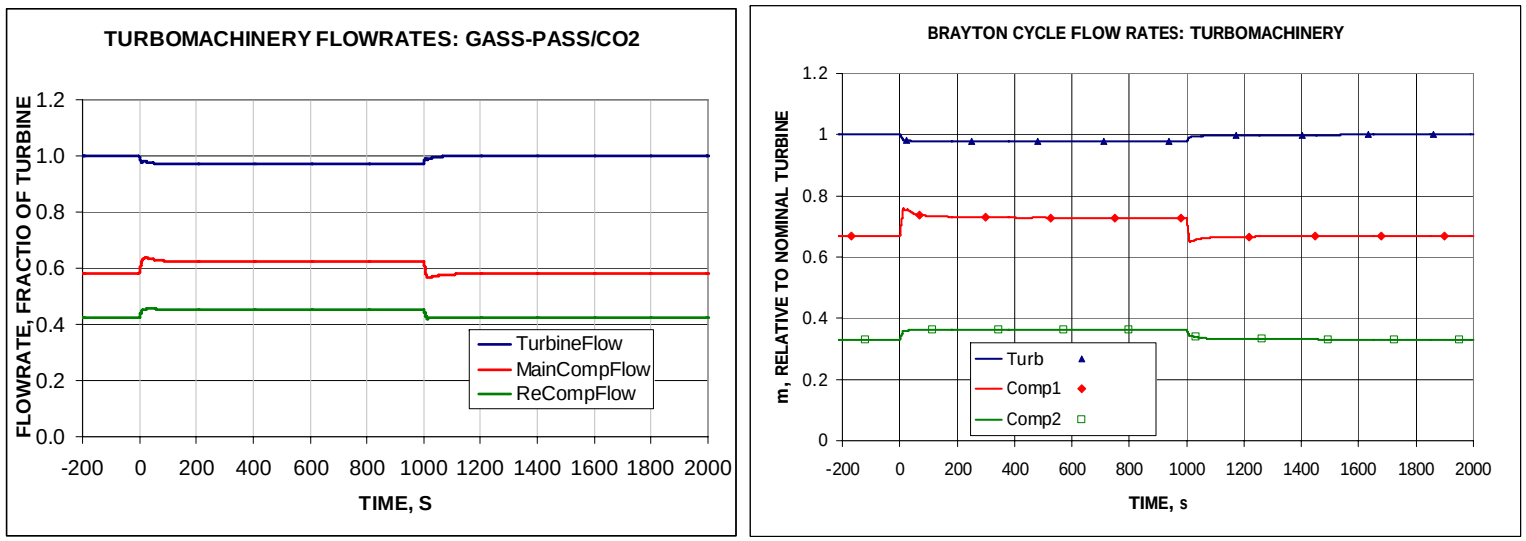

Figure 24 Step 10% Load Change Transient: Turbomachinery Flowrates

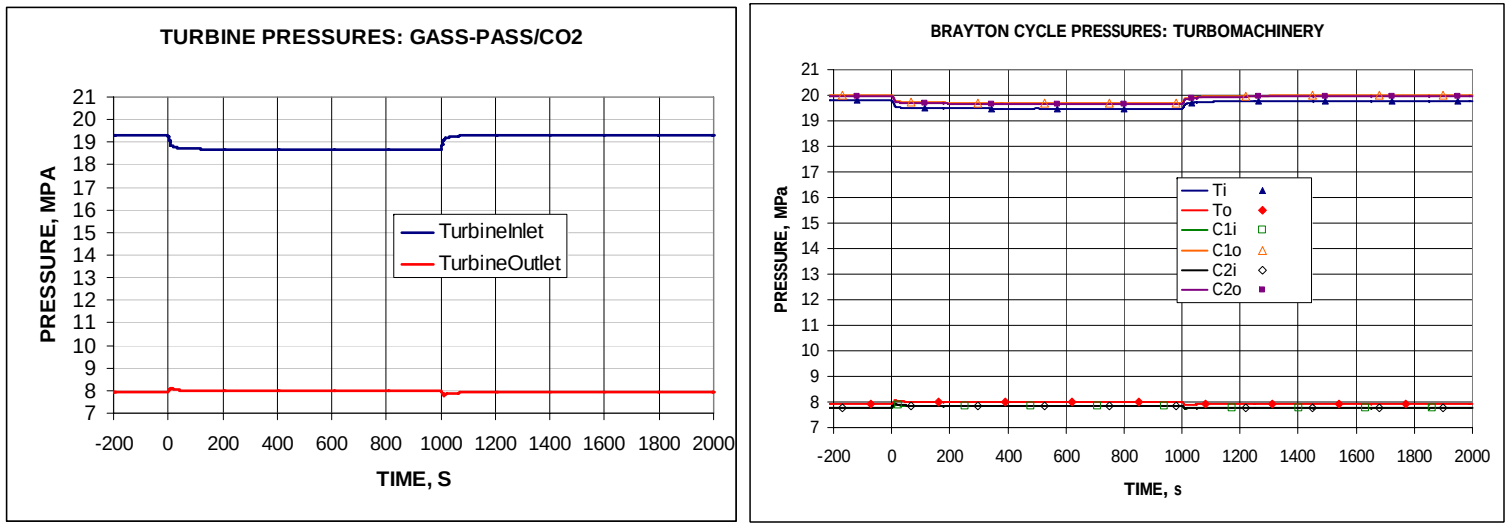

Figure 25 Step 10% Load Change Transient: Turbine Pressures

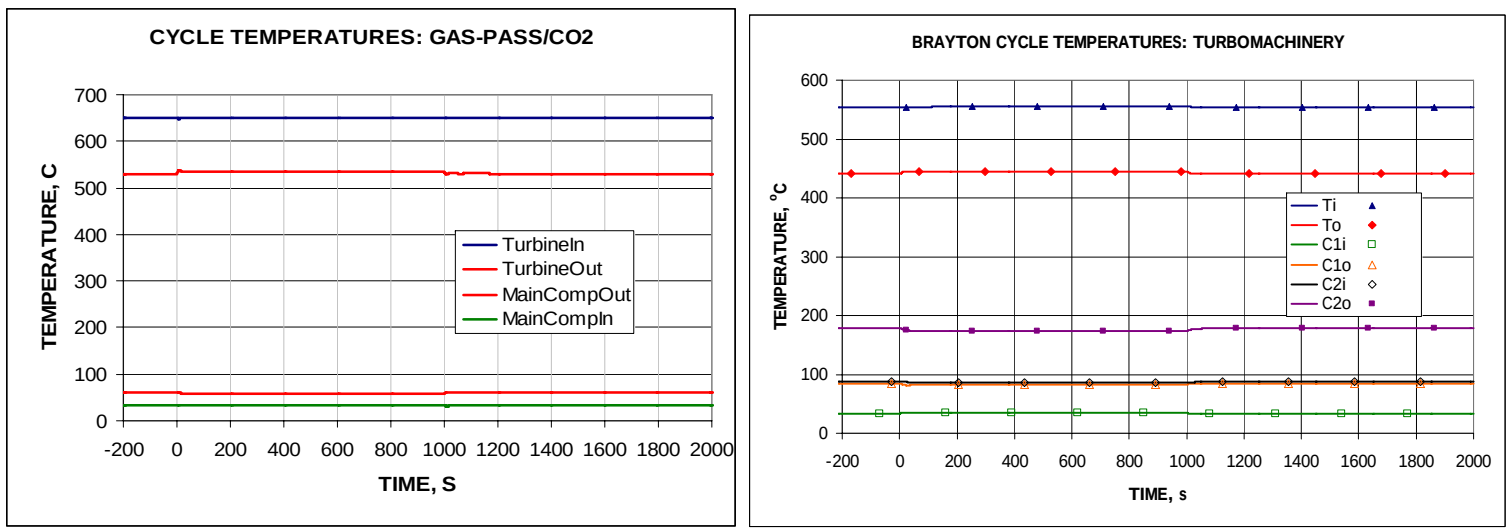

Figure 26 Step 10% Load Change Transient: Cycle Temperatures

B. Proposed

The Integrated Laboratory Scale experiment [23] underway at Idaho National Laboratory (INL) will generate data that can be used to validate the G-PASS code. In tests planned for FY09 the ILS will be run in a mode representative of an engineering-scale HTE plant. Liquid water will be pumped up to pressure, boiled, superheated, electrolyzed, and the reaction products cooled down in temperature through recuperative heat exchange. This experiment facility will be run in a manner that exercises essentially all the components in a full-scale HTE plant: pump, boiler, gas-phase heat exchanger, and electrolyzer.

The data from the ILS present an opportunity to validate G-PASS models for individual components. This includes not only the opportunity to cross-check properties but also the constitutive equations. Instrumentation on the ILS will be a key factor detrmining the degree to which separate effects can be examined.

The data from the ILS also presents an opportunity to validate G-PASS for simulating integrated system behavior. In a commercial HTE plant there are essentially four modes of operation: startup, full power operation, load change, and recirculation mode. The last mode involves switching the plant to a state, following an upset in the energy-generating plant, which maintains temperatures constant in the HTE so that components lifetimes are not shortened through large temperature changes and resulting thermal stresses. To the extent the ILS can be operated over the course of its lifetime in each of these modes, the more extensive the data base for validating codes for designing a follow-on engineering-scale facility.

The Small-Scale Test Facility under construction at Sandia National Laboratory (SNL) [21] will generate data that can be used to validate turbo-machinery models in the G-PASS code. This facility will host experiments for individual components (compressor and turbine) and for integrated experiments (turbine bypass operation and flow-split compressor operation). While the coolant will be carbon dioxide rather than helium, the loss mechanisms in individual components and the equipment configuration in system operation have their NGNP helium counterparts. Work is already underway to validate the radial compressor model in G-PASS. [18]

VIII. CONCLUSIONS

Validation is the process of determining whether the models in a computer code can describe the important phenomena in applications of interest. Past work and proposed future work for validating the Gas Plant Analyzer and System Simulator (G-PASS) code were described. Results were presented comparing code properties, individual component models, and integrated system behavior against results from four other computer codes. Also identified were two experiment facilities nearing completion that can provide data for individual component and integrated system model validation. The main goal of the validation exercise is to ready a version of G-PASS for use as a tool in evaluating vendor designs and providing guidance to vendors on design directions in nuclear-hydrogen applications.

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Nuclear Engineering Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 208
Argonne, IL 60439-4842

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