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Improvements of RELAP5/MOD3.2.2 Models for the CANDU Plant Analysis

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Abstract

The main purpose of this study is to develop a thermal hydraulic auditing analysis code for CANDU reactor by extending the model of current RELAP5/MOD3, which have been used for a long time as an auditing analysis tool of Light Water Reactors (LWR). The major thermal hydraulic phenomena for the key CANDU events and the modeling limitation of the current RELAP5/MOD3 for CANDU applications are based on the previous study on the applicability of RELAP5 code to the CANDU-type plants. The seven models are improved: the CANDU fuel channel heat transfer model; the horizontal flow regime model; the digital control model; ANS94-4 decay heat model; Moody critical model; motor operative valve model; and pressurizer spray model. The models are improved and developed on generic base, thus, they also could be applicable to PWR. Especially, the plutonium contribution to decay heat can be considered by the ANS94-4 decay heat model. The Moody critical flow model using a heavy water property can provide an additional capability to evaluate the conservative break flow in CANDU system. Simulation of different rate of opening and closing the motor valve is now possible when calculating the liquid relief vale behavior during transient. And the new pressurizer spray model can be used for evaluating the droplet size effect on the condensation. All of those improvements are verified through some assessments with simple conceptual problems and Marviken critical flow test. The new code is based on the RELAP5/MOD3.2.2 gamma version, and written in FORTRAN90 language.

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Executive Summary

A best estimate code for CANDU-type plants has been strongly requested especially in the Korea Institute of Nuclear Safety (KINS) in Korea for his regulatory purpose including the independent regulatory auditing calculation of the major design basis accidents during the licensing review and/or the safety evaluation on the operational transients and incidents experienced.

The main purpose of this study is to develop a thermal hydraulic auditing code for CANDU reactor by extending the model of current RELAP5/MOD3, which have been used for a long time aş an auditing analysis tool of Light Water Reactors (LWR). In this study, the major thermal hydraulic phenomena for the key CANDU events and the modeling limitation of current RELAP5/MOD3 for CANDU applications obtained from the previous study were used as a basis for model improvement. As results, the following model improvements were attempted and verifications of each model were performed.

1) Reactor Kinetics Model
2) Critical Flow Model
3) Horizontal Flow Regime Model in CANDU Fuel Channel
4) CANDU Fuel Element Heat Transfer Model
5) Digital Control Component Model
6) Motor Control Valve Model
7) Pressurizer Component Model

Some of the model improvement items are not only specific to CANDU reactor, but also applicable to LWR. The reactor kinetics model has been extended to use ANS94-4 standard decay heat model which has one more Pu precursor than ANS79-3 standard model. The Moody critical flow model was added as a conventional regulatory evaluation of critical discharge for two phase mixture. Improvements were also made on Critical heat flux (CHF) model and horizontal flow regime model according to the different thermal hydraulic characteristics in CANDU horizontal core bundled with 37 fuel elements. Fuel element heatup model was also implemented for the CANDU specific horizontal geometry configuration when the two phase stratification occurs. The digital process delay model was added in control component model to simulate the one of the characteristic of digital control in CANDU plant. Motor operated valve

model has been extended to have a different opening rate and closing rate as receiving open/close signals. Pressurizer spray component model ws added as a new component. Using this component, interfacial and spray characteristics could be controlled by users input model.

By the implementation of the models to RELAP5/MOD3.2.2 gamma version, RELAP5/MOD3/CANDU has been developed. The FORTRAN 77 sources were converted into FORTRAN90 language for the new CANDU version and compiled in PC Windows operating environment. The installation verifications and application capabilities have been tested through the simple conceptual problems and Maviken critical flow tests. Although it has been verified in the conceptual basis, more extensive assessment works should be followed to examine the applicability for CANDU plant analysis.

1. Introduction

The CANDU-type Pressurized Heavy Water Reactors (PHWR) have been developed by AECL in Canada and constructed in some countries including Korea during the past decades. At present time, four 600 MWe CANDU reactors [1] are operating on the Wolsung site in Korea and it becomes more and more important to guarantee the safety for CANDU type reactor in both the regulatory body and the utility company. In reality, some incidents ranging from the minor transient to the D_2O leakage have been experienced in Korean CANDU plants. Based on this situation, a best estimate code for CANDU-type plants has been strongly requested especially in the Korea Institute of Nuclear Safety (KINS) in Korea for his regulatory purpose including the independent regulatory auditing calculation of the major design basis accidents during the licensing review and/or the safety evaluation on the operational transients and incidents experienced.

AECL, as a main designer of the CANDU plants, also developed a best estimate code [2] for the system safety analysis and the code has been applied to the preparation of the safety analysis report of Wolsung Units 2, 3 and 4. Although the code was developed based on two-fluid equations and the various unique features of CANDU type reactor were included in the code, the code also had a lot of vendor-oriented models and correlations which were, in nature, conservative or not in their use. Therefore, the code may be improper to use for regulatory purpose.

As one of the code used in the regulatory analysis, the RELAP5 code [3] has been extensively applied to the Pressurized Water Reactors (PWR) safety analysis for a long while in KINS since the late 1980's. The code was introduced from the United States Nuclear Regulatory Commission (USNRC) through the International Code Assessments and Applications Program (ICAP) and the Code Applications and Maintenance Program (CAMP). Now the RELAP5 code is one of the world-wide well known code by the international cooperation on the code verification and improvement. It is, therefore, efficient for the KINS staff to develop the RELAP5-based code for the CANDU-type reactor analysis.

It seems to be successful in some audit calculations, since RELAP5 code has its own heavy water steam table and essential features for two phase characteristics. Whether it was successful or not, it also seems that some characteristics are much dependent to the CANDU system component which was not considered specifically in RELAP5. Those features can be one of the motivation of the development of the CANDU specific models and further a RELAP5/CANDU code.

This study is focused to develop a thermal hydraulic auditing code for CANDU-type plant by extending the model of the current RELAP5/MOD3. In this study, the result from the previous study was used as a basis for code improvement, i.e., the identified major thermal hydraulic phenomena for the key CANDU events and the identified modeling limitation of current RELAP5/MOD3 for CANDU applications [4, 5]. Improvements and verifications of the important models identified are described in this report.

The Chapter 2 of this report summarized the model improvement area derived from the previous study. The included models are reactor kinetics decay heat model, Moody critical flow model, horizontal flow regime model, horizontal fuel bundle heat transfer model, digital control component model, motor operated valve model, and pressurizer spray model. The basis, implementation method, and functional verification of each model are described in the Chapter 3. The summary and conclusions from the present study are discussed in Chapter 4. The modified part of the Appendix A "Input Requirements" of the RELAP5 Manual Volume 2, which provides the information required to activate the new CANDU models, is listed in the Appendix A of this report. The Appendix B lists the RELAP5 inputs used in the developmental verification. The modified source code was submitted to USNRC in May 2000 and expected to be available for the CAMP members to use.

2. Identification of Model Improvement Area

The major phenomena identifications for the important design basis accidents in CANDU plant were tried to find out the model improvement area in the RELAP5 code. The RELAP5 modeling capabilities for each phenomena of a specific accident scenario were evaluated by the expert panels. These procedures follow the well-known PIRT (phenomena identification and Ranking) process of the CSAU (Code Scaling and Uncertainty) method [4]. The identified weaknesses of RELAP5 model for CANDU were prioritized by an expert group in considering of its significance and implementation difficulties [5]. The resultant area of model improvement was shown in Table 1.

Table 1. Model Improvement Area in RELAP5/MOD3.2.2 identified for CANDU plant application

Relevant Model	Model Improvement Area	Accident
1.Flow Regime	Improvement of Horizontal Flow Regime in CANDU Fuel Channel	LOCA
2. Heat Transfer	Fuel Element Heatup when horizontal stratification occurs	LOCA
3.Decay Model	ANS94-4 Model Implementation	General
4.Critical Flow Model	Moody Two Phase Critical Flow Model	General
5.Critical Heat Flux	D_2O 37 bundle CHF Lookup Table Implementation	General
6. Control Model	Digital Sampling Time Model	Non LOCA
7. Special Component Model	7.1 Header Model (Reactor Inlet, Outlet Header)	LOCA
	7.2 Improvement of Motor Operated Valve	General
	7.3 Degasser Condenser Spray Model	Non LOCA

3. Model Extensions and Improvements

3.1 Improvement of Reactor Kinetics Model

Model Implementation

The natural uranium fuel is used in CANDU reactor core and significant amount of fissile Plutonium is produced from neutron capture in U^{238} during the burnup. Since the decay heat is determined from the fission fragment of fission material, the Pu contribution on dacay heat is more important to the natural uranium core than the enriched uranium core. Although user option has been provided in RELAP5 of using the ANS73-1, ANS79-1 and ANS79-3 model for decay heat model, there is another ANS standard decay model, ANS94-4 [6], which can describe one more isotope, Pu^{241} behavior.

Table 2. Comparison of Decay Heat Models proposed by ANS

Description	ANS71, ANS73-1	ANS79-3	ANS94-4
Isotope	Uranium	U-235,Pu-239, U-238	U-235, Pu-239, Pu-241, U-238
Experimental Data Base	K.Shure (1961)	ENDF/B-IV, Gunst,Conner,Conway,Spinrad, Unik, Findler, Johnston, Lott, Fries & Others (1971 - 1978)	Dicken, Bauming, Akiyama, Johasson, Tobias, England & Others (1981 - 1989)
Decay Group of Fisson Products	11	23 for each isotope	23 for each isotope
Treatment of Uncertainty	$t < 10^3$ +20% -40% $10^3 < t < 10^7$ +10% -20% $t > 10^7$ +25% -50%	One standard deviation is tabulated for each isotope	One standard deviation is tabulated for each isotope.
Valid Shutdown Time	$t > 10^9$ sec (~ 30 yrs)	$t > 10^9$ sec (30 yrs)	$t > 10^{10}$ sec (300 yrs)

Table 2 shows a comparison of the various decay heat models proposed by American Nuclear Society. As shown in table 2, the ANS 1979-3 model uses 3 isotopes (^{235}U, ^{238}U, ^{239}Pu) and 23 decay group for each isotope. For the CANDU application as mentioned above, the proposed ANS94-4 model which contains the Pu^{241} contribution was added as RELAP5 decay heat model.

For the usage of ANS94-4 model, user must specify 'ANS94-4' in the fission product type of the RELAP5 input which enable to activate the power fraction of Pu^{241} and power history of Pu^{241}. Appendix A describes more about the modified part of RELAP5 manual.

Verification of Model Installation

The model installation verifications are performed using a conceptual problem on single pipe with kinetic power source. As a initial condition, the followings are assumed for each decay heat model.

1) In ANS79-3 model , the power fraction of $U^{235}/U^{238}/Pu^{239}$ is assumed as 0.5/ 0.05/ 0.45, whereas in ANS94-4 model, the power fraction of $U^{235}/U^{238}/Pu^{239}/Pu^{241}$ is assumed as 0.5/ 0.05/ 0.40/ 0.05.
2) The power fraction of Pu (0.45) was allocated to each Pu isotope in using ANS94-4 model.

Figure 1 and 2 show the short term trends of total power and decay heat after a reactor trip. The decay time constant of Pu ^{241} is higher than Pu^{239}, and the decay power using ANS94-4 model is lower than power of ANS79-3 model as expected. From this comparison, it was found that the ANS94-4 decay heat model was successfully implemented into the RELAP5 code.

3.2 Implementation of Moody Critical Flow Model

Model Implementation

In reactor blowdown transients, choked or critical flow will exist at the locale of the break. A one-dimensional choked flow model developed by Ransom and Trapp was employed in RELAP5/MOD3 as a default model. The Henry-Fauske subcooled critical flow was also adopted as an optional use of RELAP5. The H-F critical model becomes a default model from RELAP5/MOD3.2.2 gamma version. Although the Henry-Fauske model requires a non-equilibrium factor and can be adjusted by user's input, the conventional Moody model for two phase flow is needed for evaluation of the conservative upper limit of discharged flow. This feature would be required by the regulatory position of evaluation of radiological amount through the spillage of primary system. For the application of PWR and PHWR both reactor types, the implementation of Moody model was started from his original equations [7,8].

$$G_c^{\,2} = H\left[\frac{2(h_0 - h_{ls} - X_e h_{fg})}{\{H(1-X_e)v_l + X_e v_g\}^2}\{(H^2-1)X_e+1\}\right] \tag{1}$$

Where

G_c = Critical Mass Flux,

h_o = stagnation enthalpy

X_e = Exit equilibrium quality

v = specific volume

H = velocity ratio (v_g/v_f)

Moody assumed the pressure and velocity ratio as independent variables, and derived the following equation for the condition of maximum critical flux at exit throat location.

$$\partial G/\partial H\,|_P = 0 \tag{2}$$

$$\partial G/\partial P\,|_H = 0 \tag{3}$$

We can derived the following slip condition by applying condition (2) using equation (1).

$$H = (v_g/v_f)^{1/3} \tag{4}$$

Substituting equation (4) in equation (1), we can derive the single equation which can be represented as a function of exit property. For a given stagnation enthalpy and pressure, the throat pressure can be determined by numerically while maximizing the equation (1). The bisection method was used for the stable searching of the maximum condition.

For the transition from subcooled critical flow model, i.e. Henry-Fauske model, the following restriction was added in the application of Moody model

If $x_0 > 0.1$: Use Moody Model

$x_0 < 0.1$: Use Henry-Fauske Model

Where x_0 means the stagnation enthalpy of upstream condition

The smoothing function between H-F model and Moody model was not applied yet in this stage. The Moody model can be activated through the optional use in Group 1 card in RELAP5. The modified part of input manuals are presented in Group 1 card of the Appendix A.

Verification of Model Installation

For the model installation verifications, two Marviken critical flow experiment[9], tests 15 and 24 were calculated by default model, Henry-Fauske model, and Moody model. The RELAP5 input for the Marviken test assessment was listed in Appendix B. Figures 3 and 4 show comparisons of break flow for each test. The calculation results using Moody model were compared with the Henry-Fauske model, Ransom-Traff mechanistic model and experimental data. As shown in Figures, the Moody model predicts the flow rate higher than Henry-Fauske model and Ransom-Traff model at the starting of two-phase flow (~20 seconds after break) as expected. As consequences, the tank is going to be empty faster and thus the two phase critical flow turns to be a steam flow more earlier. From this comparison, it was found that the Moody critical flow model was successfully implemented into the RELAP5 code.

3.3 Improvement of horizontal flow regime model for CANDU Fuel Channel

Model Implementation

The horizontal flow regime map in RELAP5 is similar to the vertical flow regime map except that the post-CHF regimes are not included, and a horizontally stratified regime replaces the vertically stratified regime. The horizontal flow regime map therefore consists of horizontally stratified, bubbly, slug, annular mist, and mist-pre-CHF regimes. The criteria for the bubbly-to-slug and the slug to annular mist regimes are also similar to those for the vertical map. The criterion defining the horizontally stratified regime is based on the one developed by Taitel and Dukler [10]. According to Taitel and Dukler, the flow field is horizontally stratified if the vapor velocity satisfies the condition $|v_g| < v_{crit}$ where v_{crit} is the gas velocity above which waves on the horizontal interface will begin the grow and is given by following Equation.

$$V_{crit} = \frac{1}{2}\left[\frac{(\rho_l - \rho_g) g \alpha_g}{\rho_g \sin\theta}\right]^{1/2} (1-\cos\theta) \tag{5}$$

The equation was derived for the case of circular pipe, and the direct application for CANDU fuel bundle channel containing 37 fuel elements should be improper in its geometrical features and thermal hydraulic features., Moreover since the RELAP5 uses the hydraulic equivalent diameter which is much smaller than CANDU channel diameter in the calculation of V_{crit}, the horizontal stratification occurs more hardly than the expectation in channel.

For the application in the CANDU fuel channel , the following critical velocity criteria proposed by Hanna (1984) in CATHENA code[11] was considered.

$$V_{crit} = \left[g \frac{\rho^*}{\rho_g \rho_l} \{ \rho_l (\frac{F_l}{\alpha_l} - F_l^*) - \rho_g (\frac{F_g}{\alpha_g} - F_g^*) \} \right]^{1/2} \tag{6}$$

$$F_k = y_i - \frac{(-1)^k}{A \alpha_k} \int y f(y) dy, \tag{7}$$

$$F_l^* = \partial F_k / \partial \alpha_k ,$$

$$\rho^* = \alpha_l \rho_l + (1-\alpha_g) \rho_g$$

where y_i = height of water-steam interface

$f(y)$ = channel width at height y

k = identification of phase (g or f)

For the simple geometry such as circular pipe and rectangle, the linear integration value can de determined analytically as a function of void fraction. Since it is impossible to derive an analytic solution for the CANDU channel in which 37 fuel elements were loaded, the pre-calculated table values with respect to void fraction were used in calculation of a critical velocity in Eq. (6) through Eq. (7).

The comparisons of critical velocity obtained from the Hanna model and Teitel Dukler model are presented in Figure 5 and 6 for low pressure and high pressure, respectively. As shown in figures, the stratification vapor velocity of Hanna model is much higher than Taitel & Dukler model. The channel diameter effect was also considered in comparisons. Instead of using a hydraulic diameter (0.75 cm) for equation (5), which is a default for RELAP5, the CANDU channel diameter (10.34 cm) was tried for Taitel & Dukler model. It is also shown that Hanna model give a higher stratification velocity at low void fraction, where fuel elements are submerged into the water.

In addition, the liquid superficial velocity effect on stratification flow is considered through the experimental observations of MR2 data [12]. According to the experimental finding, a restrictive condition was added such that the transition from the horizontal stratified flow to the fully mixed flow occurs in the range of liquid superficial velocity of 0.085 ~ 10 m/s.
In order to activate the above model, a special new component, namely 'CANCHAN' component is introduced in new features of RELAP input. The modified parts of component input are presented in the part of component input of Appendix A.

Verification of Model Installation

The horizontal stratified flow regime model was validated from the sample calculation for a simple conceptual problem. A simple pipe model, presented in Figure 7, represent the single fuel channel of typical CANDU core. The channel was filled initially with saturated water. As a boundary condition, the saturated water and steam were introduced into the channel at the various superficial velocities; j_l and j_g. The RELAP5 input for the conceptual problem was listed in Appendix B. The steady state is sustained after an initial transient and flow regimes are determined for each j_l j_g boundary condition.

Figures 8 and 9 show the predicted flow regime using a 'CANCHAN' component model and a 'PIPE' component model, respectively. As shown in comparisons of two figures, the horizontal stratification range in CANDU channel (CANCHAN) component becomes much broader than in equivalent PIPE component. This trend is expected from the model change of stratification criteria and consistent to the experimental observation as shown in Figure 10. From this comparison, it was found that the new horizontal stratified flow regime criteria was successfully implemented into the RELAP5 code.

3.4 Implementation of CANDU 37 Fuel Bundle Heat Transfer Model

Model Implementation

An important factor that affects the magnitude of heat transfer coefficients, besides obvious parameters such as velocity, is the flow field or hydraulic geometry surrounding the heat transfer surface. Although RELAP5 has various boundary geometry type options to help users communicate the flow field geometry types to the code and some number has been assigned for some of the possible geometry, the specific coding for the assigned geometry was not available yet in the current RELAP5 code.

The CANDU reactor core has horizontal fuel rods in horizontal pipes. It was also assigned as a number '124' for its boundary type, no specific coding has been implemented. After reviewing the heat transfer correlation for the case of 121-133 boundary option, we conclude that most correlation of horizontal heat transfer package in RELAP5 could be applicable generally for the CANDU reactor channel if an appropriate critical heat flux correlation would be used. Exception of this general validity of heat transfer package is one for the fuel element when the horizontal stratification occurs in CANDU fuel channel. Since each of 37 fuel elements in the channel has a different spatial location, such an effect should be considered in heat transfer calculation when horizontal stratification occurs. The following modifications of the CHF model and the heat transfer effect of horizontal stratification were attempted in the present study.

CHF Model

RELAP5 uses AECL CHF lookup tables based on tube data, and a special multiplication factor for horizontal geometry, namely horizontal flow multiplier, k6, is applied in critical heat flux calculation. The factor is determined by the degree of stratification based on the channel void fraction only.

Figure 5 shows the comparisons of RELAP5 CHF tube data and AECL 37 bundle CHF data, and the CHF tube data base and horizontal flow multiplier could not be applicable to CANDU core. Therefore we add one subroutine which can calculate CHF using AECL D_2O 37 bundle data if user selects the number 124 as CANDU core boundary type in the heat structure modeling. The modified part of input features was presented in the Appendix A. In this input feature, the following three factors concerning grid spacer effect, heated length effect, and axial flux profile among the eight factors can be used as multipliers for AECL D_2O 37 bundle CHF table and other 5 factors are fixed as a constant value, i.e. 1.0. However, the AECL D_2O 37 bundle CHF data was classified as a AECL proprietary information, the distributed subroutine was coded such that the data was actually not used when specifying the number '124' in the heat structure input.

- k_1 : Hydraulic Diameter Effect =1.0
- k_2 : Bundle Effect =1.0
- k_3 : Grid Spacer Effect : User input
- k_4 : Heated Length Effect : User Input
- k_5 : Axial Flux Profile : User Input
- k_6 : Horizontal Flow Factor = 1.0
- k_7 =1.0
- k_8 : Non aqueous factor =1.0

Horizontal Stratified Heat Transfer Model

When a horizontal stratification occurs in CANDU fuel channel, there should be a significant difference of local conditions through the elevation in a channel, such as void fraction, velocity, and sometimes pressure. Most important parameter for heat transfer would be local quality (or void fraction) and velocity. If we assume the complete separation, the water level can be calculated from the void fraction even though it is not a simple analytical formula in CANDU channel. Separated conditions for each phase are also calculated in the two fluid model. For the given elevation of each fuel element in channel, the local conditions of fuel element can be set as follows ;

If $Z_{,top,fuel} > Z_{mixture}$: $\alpha_g = 1.0$, $x = 1.0$, and $V_{mix} = V_g$

If $Z_{,bottom,fuel} > Z_{mixture}$: $\alpha_g = 0.0$, $x = 0.0$, and $V_{mix} = V_f$

If $Z_{,bottom,fuel} < Z_{mixture} < Z_{,top,fuel}$: Properties are interpolated from height basis

Where $Z_{,top}$ is a top elevation for a given fuel element in a horizontal channel and $Z_{,bottom}$ is a bottom elevation for a same element. $Z_{mixture}$ is an elevation of the two phase mixture in channel. The logic diagram of heat transfer model is given in Figure 12 and schematic diagram of fuel element in CANDU channel is given in Figure 13. The modified input feature enables the users to put the elevations of each fuel element in a CANDU channel. The modified parts of the heat structure input are presented in the Appendix A.

Verification of Model Installation

The model of 37 Bundle CHF would be validated by CHF data itself. The horizontal stratified heat transfer model was validated from the sample calculation for a simple channel conceptual problem. Figure 14 represents the single fuel channel of typical CANDU reactor core. The channel was filled initially with saturated water in 10.69 MPa. As a boundary condition, the saturated water was flow into the channel at the low speed, 0.1 m/sec. Each element of 37 fuel has a constant power 200 kw/fuel rod. The total fuel rods were modeled as two groups of upper elements and lower elements. The RELAP5 input for the channel problem was listed in Appendix B.

As progressing of transient with the heating of fuel, the void is filled in the channel and the horizontal stratification occurs. Using the present stratified heat transfer model, the upper fuel group should be heated if the mixture level falls down below the upper element. Figures 15 and 16 show comparisons of the heat transfer coefficients and the sheath (cladding) temperatures between default model and the new heatup model, respectively. As shown in Figure 15, the upper fuel group has lower heat transfer coefficients than that of lower group fuel. The upper group fuel experienced the single phase steam cooling, otherwise film boiling occurs in the lower group fuel. Consequently the heatup has been experienced in the upper part of fuel. Figure 16 shows the temperature of CADU fuel sheath. Without the stratified heat transfer model, the sheath temperature is between the trends of upper and lower group fuels. From this comparison, it was found that the new heatup model was successfully implemented into the RELAP5 code.

3.5 Implementation of Digital Sampling Model in Control Function

Model Implementation

The control system function of RELAP5 provides the capability to evaluate simultaneous algebraic and ordinary differential equations. The capability is primarily intended to simulate control systems typically used in hydrodynamic systems, but it can also model other phenomena described by algebraic and ordinary differential equations. Although the various control functions have been provided in RELAP5, it has some shortcomings for the simulation of the digital control system. Digital devices are widely used in the major part of CANDU plant, and the signals from devices are processed and controlled by digital logic. One of major differences between analog process and digital process is the procedure for digital sampling process. The digital signal are not detected on line simultaneously, but sampled in a sequential order. This sampling time is considered in newly designed control function, 'DIGITAL'. The DIGITAL control function require the user inputs for the sampling time, delay time. Appendix A provides the more details about user inputs required for DIGITAL component.

Verification of Model Installation

The blowdown problem in Edward pipe was used for the verification of DIGITAL control function. The RELAP5 input was listed in the Appendix B. The DIGITAL function was applied for processing the pressure at the volume 301 in each sampling rate of 0.05 seconds and 0.1 seconds. Figure 17 shows a comparison of the calculated pressure and the digitally processed one. As shown in the Figure 17, the digitally processed result shows stepwise changes in pressure, which remains constants during the specified sampling times. From this comparison, it was found that the digital sampling model was successfully implemented into the RELAP5 code.

3.6 Improvement of Motor Operated Valve Model

Model Implementation

The RELAP5 has a special process model for motor operated valve (MOV). This valve model has the capability of controlling the junction flow area between two control volumes as a function of time. The operation of the valve is controlled by two trips; the first one for opening the valve and the second one for closing the valve. A constant rate should be specified to control the speed at which valve area changes in the existing RELAP5 calculation. Sometimes the motor operated valve (MOV) is used for relief valve modeling for the sake of simplicity, even though RELAP5 has a detailed mechanistic relief valve model. The liquid relief valves of the typical CANDU plant have important roles of pressure regulation and have been frequently modeled as MOV that were controlled by the set points. The difficulties in modeling of relief valve as MOV come from the relief valve characteristics, which have different rates for opening and closure. For the more flexible application of the MOV model, the extra input for closure rate was designed and modeled in a CANDU version. Appendix A shows the modified part of manual for MOV input.

Installation Verification

A sample problem was calculated using different changing rates of MOV. The RELAP5 input for the problem was listed in Appendix B. Figure 18 shows the valve stem position calculated with new model. As desired, the MOV was opened at the open rate input value by opening trip signal and closed at the closure rate by closure trip signal. From this result, it was found that the new MOV model was successfully implemented into the RELAP5 code.

3.7 Implementation of Pressurizer Spray Model

Model Implementation

Usaually, the pressurizer could be modeled as a pipe component with several volumes in RELAP5 calculation. Since RELAP5 does not have a special model for pressurizer, the spray droplet sizes were determined by the flowing condition, and independent of geometry of spraying nozzles. The sprayed droplets would be almost saturated condition before arriving at water surface of PWR pressurizer component. In such condition, total heat transfer taken out from steam is not sensitive to sprayed droplet sizes. Since pressure depression by spray is governed mainly by the droplet-steam heat transfer, spray droplet size is not important in the various transients.

In the typical CANDU plant, a "degasser-condenser" component has a similar function of PWR pressurizer. However the spray water for the degasser component comes from the D_2O storage tank, in which highly subcooled heavy water is stored. The non-condensable gas may exist in a degasser-condensor. In such an environment, the sprayed water would not be saturated condition completely during falling down. Therefore, the spray droplet size becomes much more important in CANDU degasser-condenser than PWR pressurizer.

The new component named "PRIZER" is designed such that user can input the spray droplet size and the interfacial heat transfers. As a default model, the interfacial heat transfer coefficient and droplet sizes are determined as the same as RELAP5 accumulator model. The calculation model for the determination of mixture level in PRIZER component is added also for user conveniences. Appendix A shows the more detailed input scheme in PRIZER.

Installation Verification

A sample conceptual problem was calculated to confirm if the effect of the droplet size was predicted using the PRIZER component model. The RELAP5 input for the problem was listed in the Appendix B. Figures 19 and 20 show the calculated temperature distribution and pressure drop for the various droplet sizes. As shown in figures, the temperature increase of subcooled droplet is affected by droplet size and pressure drop in PRIZER component is increased by the decreasing of droplet size. From this result, it was found that the PRIZER model was successfully implemented into the RELAP5 code.

4. Summary and Conclusions

The improvement of some thermal-hydraulic models in the current RELAP5/MOD3 was made for the purpose of CANDU type PHWR application. In this study, the major thermal hydraulic phenomena for the key CANDU events and the modeling limitation of current RELAP5/MOD3 for CANDU applications obtained from the previous study were used as a basis for model improvement. The code improvement was made such that the new CANDU-related capability can be used by the selection of user option while maintaining the current RELAP5 PWR analysis capability

The seven items were improved not only for CANDU reactor but also for generic nuclear reactor system. The CANDU fuel channel heat transfer model and the flow regime model were improved to be suitable to a CANDU specific feature. The stratification criteria proper to CANDU fuel feature and the fuel element heatup process induced by stratification were newly implemented. The digital control model was mainly deduced from CANDU plant specific feature of digital control, but it could be also applied to the special processing feature of plants. By this improvement, the digitally processed signal can be simulated. Other four items, i.e. ANS94-4 decay heat model, Moody critical model, motor operative valve model and pressurizer spray model, were developed on generic base and could be applicable to PWR also. Especially, the plutonium contribution to decay heat can be considered by the ANS94-4 decay heat model. The Moody critical flow model using a heavy water property can provide an additional capability to evaluate the conservative break flow in CANDU system. Simulation of different rate of opening and closing the motor valve is now possible when calculating the liquid relief vale behavior during transient. And the new pressurizer spray model can be used for evaluating the droplet size effect on the condensation. All of those improvement were verified through some assessments with simple conceptual problems and Marviken critical flow test .

By applying those models in the RELAP5/MOD3.2.2 gamma version code, RELAP5/MOD3/CANDU version has been established [13,14]. For the sake of developer's convenience, new version was rewritten and developed by FORTRAN90 language. The developed CANDU version could be used for more realistic estimations of thermal hydraulic behavior in CANDU channel during a LOCA.

Although the functional ability of RELAP5/MOD3/CANDU version for the plant analysis was confirmed through the verifications, the model specific assessments were not performed yet. The flow regime and heat transfer model in CANDU channel should be assessed and confirmed further through the comparison with experimental data. There must be more assessments for pressurizer spray model also. One of the important CANDU specific model would be ROH/RIH (Reactor Outlet Header/ Reactor Inlet Header Model) component model. Although the ROH/RIH model was not implemented to CANDU version yet, the model should be developed in the near future.

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Appendix A

Input Manual Change for RELAP5/MOD3/CANDU

A2.1 Card 1, Developmental Model Control

This card has been added to the code for the convenience of developers in testing model improvements or new models. This card is not a standard input feature of the code. The description of this card has been added to the input requirements because several laboratories are receiving test versions to assist in the development and testing of the code. Anyone using this card must realize that they are selecting experimental options still under development. Furthermore, these options may change more frequently than the revision of this input manual. Thus, before using the options, users should obtain the brief listing of current options from the code (described below)and verify those descriptions against this manual.

The purpose of this card is to allow developers and analysts to quickly test new models by activating or deactivating a model through simple input instead of program modification, compilation, and loading. Ninety logical variables having only false or true values are provided and defined at the start of program

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Option 48 user request the use of level model when vargrav flag is turned on.
Option 51 turns off water packing in all volumes.
Option 52 turns off choking at all junctions.
Option 53 invokes the modified Henry-Fauske critical flow model.
Option 54 invokes the Moody Critical Flow Model for Two Phase
Option 56 enforces $v_g = v_f$ at alpha = 1 in fidis2.F.
Option 60 The changes that this option enabled are now part of the code.
Option 62 uses newly developed changes to Chen f factor in prednb.

CARDS 301 THROUGH 399, MINOR EDIT DATA REQUESTS

These cards are optional for NEW and RESTART problems, are required for a REEDIT problem, and are not allowed for PLOT and STRIP problems. If these cards are not present, no minor edits are printed. If

A4.2 Component Quantities

The quantities listed below are unique to certain components; for example, a pump velocity can only be requested for a pump component. The parameter is the component number, i.e., the three-digit number ccc used in the input cards.

Code	**Quantity**
ACPGTG	Accumulator vapor specific heat, C_p, at vapor temperature (J/kg K, Btu/lb °F).

ACPNIT Accumulator noncondensable specific heat, C_p, at vapor temperature (J/kg K, Btu/lb °F).
ACQTANK Total energy transport to the gas by heat and mass transfer in the accumulator (W, Btu/s)
ACRHON Accumulator noncondensable density (kg/m^3, lb/ft^3).
ACTTANK Mean accumulator tank wall metal temperature (K, °F).
ACVDM Gas volume in the accumulator tank, standpipe, and surge line (m^3, ft^3).
ACVGTG Accumulator vapor specific heat, C_v, at vapor temperature (J/kg K, Btu/lb °F).
ACVLIQ Liquid volume in the accumulator tank, standipipe, and surge line (m^3, ft^3).
AHFGTF Accumulator heat of vaporization at liquid temperature (J/kg, Btu/lb).
AHFGTG Accumulator heat of vaporization at vapor temperature (J/kg, Btu/lb).
AHFTG Accumulator liquid enthalpy at vapor temperature (J/kg, Btu/lb).
AHGTF Accumulator vapor enthalpy at liquid temperature (J/kg, Btu/lb).
AVGTG Accumulator specific volume at vapor temperature (m^3/kg, ft^3/lb).
AVISCN Accumulator noncondensable viscosity (kg/m.s, lb/ft s).
BETAV Accumulator steam saturation coefficient of expansion (K^{-1} ° F^{-1}).
CDIM GE mechanistic dryer critical inlet moisture quality.
DIM GE mechanistic dryer inlet moisture quality.
DMGDT Accumulator/time rate of change in dome vapor mass (kg/s, lb/s).
GDRY GE mechanistic separator capacity factor.
OMEGA Inertial valve disk angular velocity (rad/s, rev/min).
PMPHEAD Pump head in the pump component (Pa, lb_f in^2).
PMPMT Pump motor torque (N m, lb_f ft).
PMPNRT Calculated pump inertia (kg m^2, lb ft^2).
PMPTRQ Pump torque in the pump component (N m, lb_f ft).
PMPVEL Pump velocity in the pump component (rad/s, rev/min).
PRZLVL Pressurizer level in the PRIZER component (m, ft)
THETA Inertial valve disk angular position (deg).
TUREFF The efficiency of the turbine component.
TURPOW The power developed in the turbine component (W, Btu/s).
TURTRQ The torque developed in the turbine component (N m, lb ft).
TURVEL The rotational velocity of the turbine component (rad/s, rev/min).
VLVAREA This is the ratio of the current valve physical area to the junction area. The junction area is the fully open valve physical area for the smooth area option and the minimum of the two connecting volumes for the abrupt area change.
VLVSTEM This is the ratio of the current valve stem position to the fully open valve stem position for the motor and servo valves when the normalized stem position option is used. For the motor and servo valves when the normalized area option is used and for all the other valves, this is the ratio of the current valve physical area to the fully open valve physical area.
XCO GE mechanistic separator liquid carryover quality.
XCU GE mechanistic separator vapor carryunder quality.
XI GE mechanistic separator inlet quality.

A7.6 Pipe, Annulus Component

A pipe component is indicated by PIPE, an annulus component is indicated by ANNULUS, and a pressurizer component is indicated by PRIZER , and a CANDU Channel component is indicated by CANCHAN on Card ccc0000. The PIPE and ANNULUS components are similar, except that the ANNULUS component must be vertical and all the water is in the film (i.e., no drops) when in the annular-mist flow regime. The remaining input for both components is identical. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. For major edits, minor edits, and plot variables, the volumes in the pipe component are numbered as cccnn0000, where nn is the volume number (greater than 00 and less than 100). The junctions in the pipe component are numbered as cccmm0000, where mm is the junction number (greater than 00 and less than

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A7.6.1 Card ccc0001, Pipe, Annulus, Prizer, CanChan Information Card

This card is required for pipe components.

W1(I) Number of volumes, nv. nv must be greater than zero and less than 100. The number of associated junctions internal to the pipe is nv-1. The outer junctions are described by other components.
W2(I) Surgeline Connection Number. This word must the same format as printed in the output. The input is required for the PRIZER component and must not be entered for PIPE and ANNULUS component.
W3(R) User specified interfacial heat transfer coefficient from liquid to saturation state (W/m^2-K, Btu/hr-ft^2-F). This word is optional for a PRIZER component and must not be entered for PIPE and ANNULUS components.
W4(R) User specified interfacial heat transfer coefficient from vapor to saturation state (W/m^2-K, Btu/hr-ft^2-F). This word is optional for a PRIZER component and must not be entered for PIPE and ANNULUS components.

A7.6.2 Cards ccc0101 through ccc0199, Pipe, Annulus X-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are required, and the card numbers need not be consecutive. The words for one set are

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A7.8 Valve Junction Component

A valve junction component is indicated by VALVE on Card ccc0000. For major edits, minor edits, and plot variables, the junction in the valve junction component is numbered ccc000000.

A7.8.1 Cards ccc0101 through ccc0109, Valve Junction Geometry Cards

This card (or cards) is required for valve junction components.

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A7.8.6.4 Motor Valve.

This behaves realistically in that the valve area varies as a function of time by either of two models specified by the user. The user must also select the model for valve hydrodynamic losses by specifying either the smooth or the abrupt area change model. If the smooth area change model is selected, a table of flow coefficients must also be input as described in Cards ccc0400 through ccc0499, CSUBV Table Section A7.8.7. If the abrupt area change model is selected, a flow coefficient table cannot be input.

W1(I) Open trip number.
W2(I) Close trip number. Both the open and close trip numbers must be valid trips. When both trips are false, the valve remains at its current position. When one of the trips is true, the valve opens or closes depending on which trip is true. The transient will be terminated if both trips are true at the same time.
W3(R) Valve opening change rate (s^{-1}). If Word 5 is not entered, this quantity is the rate of change of the normalized valve area as the valve opens or closes. If Word 5 is entered, this quantity is the rate of change of the normalized valve stem position. IF Word 6 is entered, this quantity is the rate of change of the normalized valve area as the valve opens only. This word must be greater than zero.
W4(R) Initial position. This number is the initial normalized valve area or the initial normalized stem position depending on Word W5. This quantity must be between 0.0 and 1.0.
W5(I) Valve table number. If this word is omitted or input as zero, the valve area is determined by the valve change rate and the trips. If this word is input as nonzero, the valve stem position is determined by the valve change rate and the trips; and the valve area is determined from a general table containing normalized valve area versus normalized stem position. Input for general tables is discussed in Cards 202tttnn, General Table Data, Section A11. For this case, the normalized stem position is input as the argument value and the normalized valve area is input as the function value
W6(R) Valve closing change rate (s^{-1}). If this Word is not entered, this quantity is same as the rate of opening change.

A8 CARDS 1CCCGXNN, HEAT STRUCTURE INPUT

These cards are used in NEW and RESTART type problems and are required only if heat structures are described. The heat structure card numbers are divided into fields, cccgxnn.

where ccc is a heat structure number. The heat structure numbers need not be consecutive. We suggest, but the system does not require, that if heat structures and hydrodynamic volumes are related, they be given the same number.

g is a geometry number. The combination cccg is a heat structure geometry combination referenced in the heat structure input data. The g digit is provided to differentiate between different types of heat structures (such as fuel pins and core barrel) that might be associated with the same hydrodynamic volume.

x is the card type.

nn is the card number within a card type.

A8.13 Cards 1cccg501 through 1cccg599, Left Boundary Condition Cards

These cards are required. The boundary condition data for the heat structures with this geometry are entered in a slightly modified form of sequential expansion using six quantities per set for the number of heat structures with this geometry (nh sets). The modification deals with Words 1 and 2.

W1(I) Boundary volume number or general table. This word specifies the hydrodynamic volume number (of the form cccnn000f) or general table associated with the left surface of this heat structure. These are used to specify the sink temperature.

If zero, no volume or general table is associated with the left surface of this heat structure, and a symmetry or insulated boundary condition is used (i.e., a zero temperature gradient at the boundary), or a temperature of zero is used for a surface temperature or a sink temperature in boundary conditions.

A boundary volume number is entered as a positive number.
If f is 0 or 4, the volume coordinate associated values such as average volume velocity are taken from the x coordinate;

if f is 2 or 1, volume coordinate associated values are taken from the y or z axes, respectively. These numbers define the flow direction parallel with tube bundles. Any flow in other directions is vectorally added to give the cross flow mass flux. Specifying a volume coordinate not in use is an input error.

If f is 7, the 3D hydrodynamic vomule is used. Then ccc is a channel number and nn is a mesh number

A general table is entered as a negative number (-1 through -999).
W2(I) Increment. This word and Word 1 of this card are treated differently from the standard sequential expansion. Word 1 of the first set applies to the first heat structure of the heat structure geometry set. The increment (normally 10000) is added to Word 1, which results in the hydraulic cell number associated with heat structure 2; etc. The increment is applied up to the limit in Word 6 of a set. Word 1 of the next set applies to the next heat structure, and increments are applied as for the first set. The increment may be zero or nonzero, positive or negative. If Word 1 is zero, this word should be zero. Additional examples are shown in Section 4 of Volume V.
W3(I) Boundary condition type.

If 0, a symmetry or insulated boundary condition is used (i.e., a zero temperature gradient is used at the boundary). The boundary volume must be 0.

If 1 or 1nn, a convective boundary condition where the heat transfer coefficient obtained from Heat Transfer Package 1 is used. The sink temperature is the temperature of the boundary volume. Word 1 must specify a boundary volume with this boundary condition type. The boundary volume cannot be a time-dependent volume.

There are several numbers allowed for Word 3 to activate convective boundary conditions for nonstandard geometries. A 1, 100, or 101 give the default values. The default convection and boiling correlations were derived mainly based on data from internal vertical pipe flow. Other possible input values are shown in Table A8.13-1. When modelling a vertical bundle, the rod or tube pitch-to-diameter ratio should be input on the 901 card. This has the effect of increasing the convective part of heat transfer such that users can input the true hydraulic diameter and get reasonable predictions.
Table A8.13-1 Card 501 and 601 Word 3 convection boundary type.

Word 3	Geometry Type
1,100,101	Default
102	Parallel plates (ORNL, ANS reactor; set gap and span on ccc3101-ccc3199 hydro cards for pipes and ccc0111 hydro card for single volumes and branches, set b = 2 in volume control flag on ccc1001-ccc1099 hydro cards for pipes and ccc0101-ccc0109 hydro cards for single volumes and branches).
106	Vertical annulus (CHF using KNOEBEL correlation for KMRR DUPIC Test Loop)
110	Vertical bundle without crossflow (set P/D on 801/901 card)
124	**CANDU Fuel Bundle Element Heat Transfer**
130	Flat plate above fluid
134	Horizontal bundle

If 1000 , the temperature of the boundary volume or the temperature from the general table (as specified in Word 1) is used as the left surface temperature. If Word 1 is zero, the surface temperature is set to zero.

If 1xxx , the temperature in general Table xxx is used as the left surface temperature.

If 2xxx , the heat flux from Table xxx is used as the left boundary condition.

If 3xxx , a convective boundary condition is used where the heat transfer coefficient as a function of time is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume or from the table specified in Word 1. If Word 1 is

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A8.17 Cards 1cccg801 through 1cccg899, Additional Left Boundary Cards

These cards are required whenever the left boundary communicates energy with the left hand fluid volume. The cards are in sequential expansion format, nine words per set, describing nh heat structures. Sequential expansion would only be used where the critical heat flux value was not of importance, since the length to all heat structures in the expansion would be the same. Words 2-8 are used for the CHF correlation.

Nine-word format:

W1(R) Heat transfer hydraulic diameter (i.e., heated equivalent diameter) (m, ft). This is 4*(flow area)/(heated perimeter) and is recommended to be greater than or equal to the volume hydraulic diameter since (heated perimeter) < (wetted perimeter). It is possible to input this diameter to be less than the volume hydraulic diameter. If Word 1 equals 0.0, the volume hydraulic diameter is used.
W2(R) Heated length forward (m, ft). Distance is from the heated inlet to the center of this slab. This quantity will be used when the liquid volume velocity is positive or zero. This is used to get the hydraulic entrance length effect. This is used only for the CHF correlation. It must be >0. To ignore the length effect, put in a large number (i.e., > 10.0).

W3(R) Heated length reverse (m, ft). Distance is from the heated outlet to the center of this slab. This quantity will be used when the liquid volume velocity is negative. This is used to get the hydraulic entrance length effect. This is used only for the CHF correlation. It must be >0. to ignore the length effect, put in a large number (i.e., > 10.0).

W4(R) Grid spacer length forward (m, ft). Distance is from the center of this slab to the nearest grid or obstruction upstream. This quantity will be used when the liquid volume velocity is positive or zero. This is used to get the boundary layer disturbance and atomization effect of a grid spacer in rod bundles. This is used only for the CHF correlation. If the grid K loss (Word 6) is zero, Word 4 is not used.

W5(R) Grid spacer length reverse (m, ft). Distance is from the center of the slab to the nearest grid or obstruction downstream. This quantity will be used when the liquid volume velocity is negative. This is used to get the boundary layer disturbance and atomization affect of a grid space in rod bundles. This is used only for the CHF correlation. If the grid K loss (Word 7) is zero, Word 5 is not used.

W6(R) Grid loss coefficient forward. Used for forward flow in rod bundles. This quantity is used when the liquid volume velocity is positive or zero. This is used only for CHF calculation.

W7(R) Grid loss coefficient reverse. Used for reverse flow in rod bundles. This quantity is used when the liquid volume velocity is negative. This is used only for the CHF correlation.

W8(R) Local boiling factor. Enter 1.0 if there is no power source in the heat structure or if the local equilibrium quality is negative (i.e., liquid is subcooled and void is zero). This is the local heat flux/average heat flux from start of boiling. If the power profile is not flat, a steady state run may help determine this number. This number must be greater than 0.0.

W9(I) Heat structure number.

Twelve-word format (Word 1 = 1 on Card 1cccg800). The first eight words of this format is identical to the nine-word format.

W9(I) Natural circulation length (m, ft). This should be the height of a hydraulic natural convection cell. For a heated vertical plate, this is the total height of the plate. For inside a horizontal tube, this should be the inside tube diameter. For the outer surface of vertical or horizontal bundles, it is suggested to use the heated bundle height in the vertical direction. When using the nine word format, this quantity is set to Word 1, the heat transfer hydraulic diameter.

W10(R) Rod or tube pitch-to-diameter ratio (P/D). The default is 1.1. The maximum is 1.6. It is not used unless Word 3 on the 501 card is 110, 111, 114 or 135. If CANDU geometry (124 Option on 501 CARD) was selected, this value is relative height of fuel element, and value should be within +/- 1.0.

W11(R) Fouling factor. This factor is applied to the heat transfer correlations and may be used to represent fouling or to run sensitivity studies. This quantity must be a positive nonzero number. When using the nine-word format, this quantity is set to 1.0.

W12(I) Heat structure number.

Thirteen-word format (Word 1 = 2 on Card 1CCCG800). Set Word 1 = 0. Words 9, 10, and 11 of this format are identical to the twelve-word format.

A12.1 Card 30000000, Reactor Kinetics Type Card

This card is required.

W1(A) Kinetics type. Enter POINT or DELETE. Enter POINT for the point reactor kinetics option. Enter DELETE in a restart problem if reactor kinetics is to be deleted. No other data are needed if reactor kinetics is being deleted.

A12.3 Card 30000002, Fission Product Decay Information

This card is optionally entered for POINT problems if W1 of Card 30000001 contains GAMMA or GAMMA-AC. If this card is not entered, the Proposed 1973 ANS Standard fission product data are used if default data are used.

W1(A) Fission product type. Enter ANS73, ANS79-1, or ANS79-3, or ANS94-4

If default fission product data are used, ANS73 specifies the Proposed 1973 ANS Standard data, ANS79-1 specifies the 1979 Standard data for 235 U, and ANS79-3 specifies the 1979 ANS Standard data for the three isotopes, 235 U, 238 U, and 239 Np. ANS94-4 specifies the 1994 ANS Standard data for the four isotopes, 235 U, 238 U, 239 Pu, 241 Pu. ANS79-3 and ANS94-4 also requires that power fractions for each isotope must be entered

If fission product data are entered, ANS73 and ANS79-1 specify only one isotope and ANS79-3 specifies three isotopes and also requires that the number of decay heat groups for each isotope be entered.
W2(R) Energy release per fission (MeV/fission). If not entered or zero, the default value of 200 MeV/fission is used.
W3-W5(R) If ANS79-3 or ANS94-4 is specified in W1, the fraction of power generated in 235 U, 238 U, and 239 Pu ,or 241 Pu must be entered in these three or four words. The sum of the fractions must add to one.
W6-W8(I) Number of groups per isotope. If ANS79-3 or ANS94-4 is entered in W1 and default data are not being used, the number of decay groups for 235 U, 238 U, and 239 Pu or 241 Pu must be entered in these three or four words. The number of groups for each isotope must be less than or equal to 50.

A12.7 Cards 30000401 through 30000499, Power History Data

If these cards are not present, initial conditions for fission product and actinide groups are for steady- state operation at the power given in W2 of Card 30000001. This is equivalent to operation at that power for an infinite time. If these cards are present, the power history consisting of power and time duration is used to determine the fission product and actinide initial conditions. The power from gamma and actinide decay is assumed to be zero at the beginning of the first time duration. Data are entered in three- or six- word sets, one or more sets per card. Card numbers need not be consecutive.

W1(R) Reactor power (W). This quantity is the total reactor power, that is, the sum of fission power and decay power, and must be > 0. If a decay power obtained from the power history exceeds this quantity, the fission power is assumed to be zero.
W2(R) Time duration. Units are as given in next word. This quantity must be greater than or equal to 0.
W3(A) Time duration units. Must be sec, min, hr, day, or wk.

W4-W7(R) Power fractions. If ANS79-3 or ANS94-4 is entered in W1 of Card 30000002, the power fractions for 235 U, 238 U, and 239 Pu or 241 Pu must be entered in these words.

A14 CARDS 205CCCNN OR 205CCCCN, CONTROL SYSTEM INPUT DATA

These cards are used in NEW and RESTART problems if a control system is desired. They are also used to define the generic control components employed with the self-initialization option. Input can also be used to compute additional quantities from the normally computed quantities. These additional quantities can then be output in major and minor edits and plots.

Two different card types are available for entering control system data, but only one type can be used in a problem. The digits ccc or cccc form the control variable number (i.e., control component number). The card format 205cccnn allows 999 control variables, where ccc ranges from 001 through 999. The card format 205ccccn allows 9999 control variables, where cccc ranges from 1 through 9999.

If the self-initialization option is selected, the data cards described in Section A14.2, Section A14.3.20, and Section A14.3.21 must be included. If loop flow control is to be included, the data cards described in Section A14.3.19 must also be included.

A14.2 Card 205ccc00 or 205cccc0, Control Component Type Card

One card must be entered for each of the generic control components when using the self-initialization option.

W1(A) Alphanumeric name. Enter a name descriptive of the component. This name will appear in the printed output along with the component number. A limit of 10 characters is allowed for CDC 7600 computers, and a limit of 8 characters is allowed for most other computers.
W2(A) Control component type. Enter one of the component names, SUM, MULT, DIV, DIFFRENI, DIFFREND, INTEGRAL, FUNCTION, STDFNCTN, DELAY, TRIPUNIT, TRIPDLAY, POWERI, POWERR, POWERX, PROP-INT, LAG, LEAD-LAG, CONSTANT, SHAFT, PUMPCTL, STEAMCTL, or FEEDCTL, or DIGITAL, or the command DELETE. If DELETE is entered, enter any alphanumeric word in Word 1 and zeros in the remaining words. No other cards are needed when deleting a component.
W3(R) Scaling factor. For a CONSTANT component, this quantity is the constant value. No additional words are entered on this card, and Cards 205ccc01 through 205ccc09 or 205cccc1 through 205cccc9 are not entered. For the PUMPCTL, STEAMCTL, or FEEDCTL components, this is the gain multiplier (G) for the output signal.
W4(R) Initial value.
W5(I) Initial value flag. Zero means no initial condition calculation and W4 is used as the initial condition; one means compute initial condition.
W6(I) Limiter control. Enter zero, or omit this and the following words if no limits on the control variable are to be imposed. Enter 1 if only a minimum limit is to be imposed, 2 if only a maximum limit is to be imposed, and enter 3 if both minimum and maximum limits are to be imposed.

A14.3.8-1 Digital Component

This component is indicated by DIGITAL in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S\ V_1\ f\{t_s\}(t - t_d)$$

where t is time and t d is the delay time.

W1(A) Alphanumeric name of the variable request code for V_1.
W2(I) Integer name of the variable request code for V_1.
W3(R) Sampling time, t_s (s).
W4(R) Delay time, t_d (s).

Appendix B

Input Decks for the Validation of Model Implementation

B.1 Input for ANS94-4 Decay Model Validation

```
= Short term decay heat study
*                       Configuration Control Problem
*  Input contains minimum hydrodynamics to allow testing of reactor
*  kinetics and decay heat calculation for long time periods.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*1  86 * mod3.2.2 deactivate time control
100 new transnt
104 none
301 rktpow  0
302 rkfipow 0
303 rkgapow 0
304 rkreac  0
*  time step control
201 100.0 1.0-7 0.01 7 100 10000 10000
*
0030000 edwards pipe
0030001 2
0030101 4.56037-3,2
0030301 2.04801-1,2
0030601 0,2
0030801 1.177911-6,0,2
0031001 0,2
0031101 0,1
0031201 0,7.0+6,9.78293+5,2.58184+6,0,0,2
0031301 0,0,0,1
* reactivity table
20201100 reac-t
20201101 -1.0,0.0
20201102  0.0,0.0
20201103  5.0,0.0
20201104  5.1,-5.0
20201105  5.2,-5.0
20201106  12.0,-5.0
20201107  12.1,-5.0
20201108  40.0,-5.0
* reactor kinetics input
30000000 point
30000001 gamma-ac  1.0+6  -1.0-20  200.0 1.0 1.0  1.0 52.0 wk
30000002 ans94-4  200.0  0.50  0.05  0.40 0.05
*30000002 ans79-3  200.0  0.50  0.05  0.45
30000011 11
30000401 1.0+6  200.0 wk  0.71  0.13  0.10 0.06
*30000401 1.0+6  200.0 wk  0.81  0.13  0.06
. end of case
```

B.2 Input for Digital Control Model Validation

```
=edward's pipe problem base case with extras and heavy water
*                    Configuration Control Problem
*       This problem is the same as edhtrk except that heavy water is
*  used instead of light water.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
0000100 new transnt
20800001  dt 0
20800002  dtcrnt 0
20800003  count 0
20800004  errmax 0
```

```
20530001 cntrlvar,13  0.1  10
*
20530100 ctl301 digital 1.0 0.0 1
20530101 p,3010000  0.05  0.0
*
20530200 ctl302 digital 1.0 0.0 1
20530201 p,3010000  0.10  0.01
*
20530300 ctl303  lead-lag  10.0  0.0  1
20530301 0.05  0.1  time,0
```

B.3 Input for Validation of Motor Valve Model

```
=typical pwr model  4 inch cold leg break 36.05 check case
*                        Configuration Control Problem
*       This problem is a simulation of a four loop presurized reactor
*  undergoing a small break.  Loop containing break is modeled as a
*  single loop but the other three loops are coalesced into one loop.
*  Modeling does not now follow all recommended modeling practices but
*  problem is still good test of many features of code.  Problem uses
*  standard matrix techniques.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
100 new transnt
*
102  british   british
105  5.0 6.0 5000.0
110 nitrogen
***********************************************************************


593  time   0              le   null   0      30.0      n * close
592  time   0              ge   null   0      10.0      n * close
591  time   0              ge   null   0      40.0      n * open
*
601  603  and   509  n   -1.0
602  601  or    508  n   -1.0
603  602  and   509  n   -1.0
511  voidg  172010000     le   null   0      0.30838   n
512  voidg  172010000     ge   null   0      0.39578   n
604  505  and   511  n   -1.0
605  505  and   512  n   -1.0
606  608  and   604  n   -1.0
607  606  xor   605  n   -1.0
608  607  and   605  n   -1.0
691  592  and   593  n   -1.0
*
*
120 100010000 0.0 d2o primary
121 170010000 0.0 h2o secnd-1 1
122 270010000 0.0 h2o secnd-2 1
***********************************************************************



1850000    "imainstm"  valve
1850101    180010000  186000000   13.29  0.0  0.0  0100
1850201    1     0.0     2914.71   0.0
1850300    mtrvlv
*          open  close rate   init  trip  rate
1850301    510   501   0.20   1.0   0     0.1
1850301    591   691   0.20   1.0   0     0.1
*
```

B.4 Input for Validation of Moody Critical Flow Model

```
=marviken test 15 (case 1)
*
** problem type and option
*
*  option 54 for Moody critical flow model
*  option 50 for Traff-Ransom
*  defalt option Henry-Fauske
*
1         54
*1        50
*
0000100    new transnt
0000102    si          si
0000105    3.0    4.0
*
*120 003010000 0.0 d2o section
*
** time step control cards -
*
*card #  t-end    dtmin     dtmax    control    minor    major    restart
0000201  5.00     1.0e-7    0.005        1        20       200      4096
0000202  20.0     1.0e-7    0.005        1        50      1000      4096
0000203  80.0     1.0e-7    0.250        1         2        40      4096
*
*-  minor edit requests -
*
0000301  p         3010000
0000302  p         3390000
0000303  p         5060000
0000304  rho       3390000
0000305  rho       5030000
0000306  voidg     3390000
0000307  voidg     5060000
0000308  mflowj    9000000   * discharge
0000309  mflowj    5050000
0000310  tempf     8030000
0000311  tempg     8030000
0000312  p         8020000
0000313  p         8030000
0000314  voidg     8020000
0000315  voidg     8030000
0000316  rhof      8030000
0000317  rhog      8030000
0000318  sounde    8030000
0000319  voidgj    8020000
0000320  voidgj    9000000
0000321  sattemp   8030000
0000322  velfj     9000000
0000323  quale     8030000
0000324  cputime   0
0000325  cntrlvar  1         * nozzle pressure
0000326  xej       9000000   * discharge
*
** hydrodynamic components
*
*- vessel component -
*
0030000  vessel   pipe
0030001  39
0030101  0.0      39
0030201  0.0      37   17.0     38
0030301  3.55      1   1.0       2   0.5      38   1.26     39
0030401  8.547     1   13.9      2   10.036    3   10.501    4   10.8125   13
0030402  10.767   17   10.373   18   10.76    19   9.05     20
0030403  10.5     24   10.45    28   10.319   37   10.098   38   19.68     39
0030601  -90.0    39
0030801  0.0          0.0       39
0031001  0       39
0031101  000     38
*
** pipe volume initial conditions
*card # control pressure  quals   zero  zero  zero  vol.no
0031201    2    5.04e6    1.0     0.0   0.0   0.0   1
0031202    2    5.04e6    1.0     0.0   0.0   0.0   2
0031203    2    5.04e6    0.00504 0.0   0.0   0.0   3
0031204    2    5.046e6   0.0     0.0   0.0   0.0   4
0031205    2    5.050e6   0.0     0.0   0.0   0.0   5
0031206    2    5.053e6   0.0     0.0   0.0   0.0   6
0031207    2    5.058e6   0.0     0.0   0.0   0.0   7
0031208    2    5.061e6   0.0     0.0   0.0   0.0   8
*card # control pressure  temp    zero  zero  zero  vol.no
0031209    3    5.065e6   537.0   0.0   0.0   0.0    9
0031210    3    5.069e6   536.5   0.0   0.0   0.0   10
```

```
0031211    3    5.073e6    536.3    0.0    0.0    0.0    11
0031212    3    5.077e6    536.0    0.0    0.0    0.0    12
0031213    3    5.080e6    535.0    0.0    0.0    0.0    13
0031214    3    5.084e6    534.2    0.0    0.0    0.0    14
0031215    3    5.088e6    532.4    0.0    0.0    0.0    15
0031216    3    5.092e6    530.5    0.0    0.0    0.0    16
0031217    3    5.096e6    521.9    0.0    0.0    0.0    17
0031218    3    5.100e6    513.3    0.0    0.0    0.0    18
0031219    3    5.104e6    508.9    0.0    0.0    0.0    19
0031220    3    5.108e6    508.9    0.0    0.0    0.0    20
0031221    3    5.112e6    508.9    0.0    0.0    0.0    21
0031222    3    5.116e6    508.5    0.0    0.0    0.0    22
0031223    3    5.120e6    508.5    0.0    0.0    0.0    23
0031224    3    5.124e6    508.5    0.0    0.0    0.0    24
0031225    3    5.128e6    508.5    0.0    0.0    0.0    25
0031226    3    5.132e6    508.0    0.0    0.0    0.0    26
0031227    3    5.136e6    508.0    0.0    0.0    0.0    27
0031228    3    5.140e6    508.0    0.0    0.0    0.0    28
0031229    3    5.144e6    508.0    0.0    0.0    0.0    29
0031230    3    5.148e6    508.0    0.0    0.0    0.0    30
0031231    3    5.152e6    508.0    0.0    0.0    0.0    31
0031232    3    5.156e6    508.0    0.0    0.0    0.0    32
0031233    3    5.160e6    508.0    0.0    0.0    0.0    33
0031234    3    5.164e6    508.0    0.0    0.0    0.0    34
0031235    3    5.168e6    508.0    0.0    0.0    0.0    35
0031236    3    5.172e6    508.0    0.0    0.0    0.0    36
0031237    3    5.176e6    508.0    0.0    0.0    0.0    37
0031238    3    5.180e6    508.0    0.0    0.0    0.0    38
0031239    3    5.188e6    508.0    0.0    0.0    0.0    39
*
* card #   velf    velg    vjun   jun.no
0031301    0.0     0.0     0.0      38
*
*- single junction outlet from vessel
*
0040000    outletj     sngljun
0040101    003010000    005000000    2.0    0.0    0.0    1000
0040201    0        0.0     0.0      0.0
*
*- pipe component
*
0050000    discharg    pipe
0050001    6
0050102    0.4441      3
0050103    0.4778      5
0050104    0.4441      6
0050201    0.0         5
0050304    1.1770      3
0050305    0.8890      5
0050306    1.0000      6
0050501    0.0         6
0050601    -90.0       6
0050801    0.0       0.0      6
0050901    0.0       0.0      5
0051001    0           6
0051103    1000        2
0051104    1100        3
0051105    1000        4
0051106    1100        5
*
*card # cntl   pressure    temp     zero   zero   zero   vol.no
0051221    3    5.197e+6    503.50   0.0    0.0    0.0    1
0051222    3    5.207e+6    499.00   0.0    0.0    0.0    2
0051223    3    5.217e+6    488.00   0.0    0.0    0.0    3
0051224    3    5.225e+6    477.00   0.0    0.0    0.0    4
0051225    3    5.233e+6    460.80   0.0    0.0    0.0    5
0051227    3    5.241e+6    450.50   0.0    0.0    0.0    6
*
0051300       0
0051301    0.0     0.0     0.0       5
*
*- single junction from discharge to nozzle
*
0060000    dischj    sngljun
0060101    5010000    8000000    0.19634954    0    0    1000
0060201        0     0.0     0.0      0.0
*
*- nozzle component
*
0080000    nozzle    pipe
0080001    3
0080101    0.196349541    3
0080201    0.196349541    2
0080301     0.6000       1
0080302     0.6000       2
0080303     0.6090       3
0080401     0.           3
```

```
0080501    0.0        3
0080601   -90.0       3
0080801       0.0          0.0        3
0080901   0.0    0.0     2
0081001       0        3
0081101     1000       2
*
** pipe volume initial conditions

*card #   cntl  pressure   tempf   zero   zero   zero   vol.no
0081201    3    5.246e+6   450.5   0.0    0.0    0.0    1
0081202    3    5.252e+6   450.5   0.0    0.0    0.0    2
0081203    3    5.259e+6   450.5   0.0    0.0    0.0    3
*
0081300   0
0081301   0.0     0.0      0.0     2
*
*- single junction outlet from nozzle
*
0090000   outltj   sngljun
0090101   8010000   7000000   0.19634954   0   0   000
*0090101   8010000   7000000   0.19634954   0   0   0000  1.0  0.0001   0.0  *HEM
*0090101   8010000   7000000   0.19634954   0   0   0000  1.0  1000.0   0.0  *FROZEN
0090201     0        0.0     0.0       0.0
*
*- time dependent outlet volume -
*
0070000   outltv   tmdpvol
0070101   0.2035   1.0   0.0     0.0     -90.0    -1.0     0.0      0.0    0
0070200     2
0070201   0.0      1.0+5      1.0
*
*- control variables
*
20500100  nozpres    sum       1.0        0.0        1
20500101  0.0        0.001     p        005060000
*
.
```

B.5 Input for CANDU Channel Flow Regime and Fuel Heatup Model Validation

```
= CANDU Fuel Heatup Test
*****************************************************************
*  Sample Input deck developed by B.D.Chung 12/10/1999
*  12 channel with CANDU fuel problem
*  Water and Steam is injected into the channel
*****************************************************************
*   running type
*
100  new  transnt
101  run
102  si     si
105  2.  4.
110  nitrogen
115  1.0
*
120   100010000   0.0      d2o      channel
*
201  500.   1.0e-6  0.1   3   10   1000   10000
****************************************************
*   minor edit volumes
*-
*    alp num
*-
301    p  100010000         * channel in  pressure
302    p  100120000         * channel out pressure
311    voidg   100010000
312    voidg   100120000
321    mflowj  018000000    * channel inlet flow
322    mflowj  101000000     * channel outlet flow
*
335    cntrlvar        1
336    cntrlvar        2
337    floreg  100060000
*
340   htmode    100100801
341   htmode    100200801
350   hthtc     100100801
351   hthtc     100200801
360   httemp    100100806
361   httemp    100200806
*
***********************************************************
*
0170000   feedliq tmdpvol
0170101   10.0  0.0  1000.0  0.0  0.0  0.0  0.0  0.0  0
0170200   202
0170201   0.0       10.69e6   0.0
0170202   50000.0  10.69e6   0.0
*
0180000    feedjun  tmdpjun
0180101    017000000  100000000  0
* natural circulation 1%
0180200    0
0180201    0.        0.1  0.0   0. * jf
*
0190000   feesteam tmdpvol
0190101   10.0  0.0  1000.0  0.0  0.0  0.0  0.0  0.0  0
0190200   202
0190201   0.0       10.69e6   1.0
0190202   50000.0  10.69e6   1.0
*
0200000    feedjun  tmdpjun
0200101    019000000  100000000  0
* natural circulation 1%
0200200    0
0200201    0.        0.00  0.0   0. * jg
****************************************************
*  Heated Section Pipe
*
1000000    chanl        canchan
1000001    12
1000101    0.330125     12
1000101    8.397-03     12
1000201    0.0          11
1000301    0.4953       12
1000401    0.0          12
1000501    0.0          12
1000601    0.0          12
1000701    0.0          12
1000801    4.51e-5      0.007518    12
1000901    0.939        0.939   11
1001001    100          12
```

```
1001101    100         11
1001201    202    10.69e6    0.0     0. 0. 0.   12
1001300    1
1001301    0.0    0.0    0.0    11
*          Dj
1001401    0.007518 0.0    1.0    1.0   11
*********************************************************
1010000    jun882   sngljun
1010101    100010000 102000000    0.0    0.10    0.10   100
1010102    0.61  0.61  0.61
1010201    1    0.0    0.0    0.0
*
1020000   outvol tmdpvol
1020101   10.0  0.0  1000.0  0.0  0.0  0.0  0.0  0.0  0
1020200   203
1020201   0.0       10.69e6    562.0
1020202   50000.0  10.69e6    562.0
*
*
* heat structure of channel 1 core
*
* top 18 fuel rods
*
11001000    12     6     2     1     0.0
11001100    0     1
11001101    3     0.0061
11001102    1     0.00615
11001103    1     0.00655
11001201    3   3
11001202    6   4
11001203    4   5
11001301    1.0   5
11001400    0
11001401    1000.0   4      600.0    5      590.0    6
*11001501    0              0        0   1    1740.98     12
*11001601    100010000     10000     124 1    1740.98     12
11001501    0              0        0   1    18.00       12
11001601    100010000     10000     124 1    18.00       12
11001701    50    0.0231    0.0    0.0    1
11001702    50    0.0570    0.0    0.0    2
11001703    50    0.0840    0.0    0.0    3
11001704    50    0.1026    0.0    0.0    4
11001705    50    0.1157    0.0    0.0    5
11001706    50    0.1235    0.0    0.0    6
11001707    50    0.1235    0.0    0.0    7
11001708    50    0.1158    0.0    0.0    8
11001709    50    0.1009    0.0    0.0    9
11001710    50    0.0798    0.0    0.0    10
11001711    50    0.0528    0.0    0.0    11
11001712    50    0.0213    0.0    0.0    12
11001801    0.0    10.0    10.0    0.0    0.0    0.0    0.0    1.0    12
*
*11001901    0.0    10.0    10.0    0.0    0.0    0.0    0.0    1.0    12
* if 124 option, word 10 is the relative elevation
* of fuel in a channel -1.0 < z < 1.0
*
11001900    1   * 12 word format
11001901    0.0    10.0    10.0    0.0    0.0    0.0    0.0    1.0
+           0.0    0.5     1.0     12
*
* bottom 19 fuel rods
*
11002000    12     6     2     1     0.0
11002100    0     1
11002101    3     0.0061
11002102    1     0.00615
11002103    1     0.00655
11002201    3   3
11002202    6   4
11002203    4   5
11002301    1.0   5
11002400    0
11002401    1000.0   4      600.0    5      590.0    6
*11001501    0              0        0   1    1740.98     12
*11001601    100010000     10000     124 1    1740.98     12
11002501    0              0        0   1    19.00       12
11002601    100010000     10000     124 1    19.00       12
11002701    50    0.0231    0.0    0.0    1
11002702    50    0.0570    0.0    0.0    2
11002703    50    0.0840    0.0    0.0    3
11002704    50    0.1026    0.0    0.0    4
11002705    50    0.1157    0.0    0.0    5
11002706    50    0.1235    0.0    0.0    6
11002707    50    0.1235    0.0    0.0    7
11002708    50    0.1158    0.0    0.0    8
11002709    50    0.1009    0.0    0.0    9
11002710    50    0.0798    0.0    0.0    10
```

```
11002711    50   0.0528   0.0   0.0   11
11002712    50   0.0213   0.0   0.0   12
11002801    0.0   10.0   10.0   0.0   0.0   0.0   0.0   1.0   12
*
*11002901   0.0   10.0   10.0   0.0   0.0   0.0   0.0   1.0   12
* if 124 option, word 10 is the relative elevation
* of fuel in a channel -1.0 < z < 1.0
*
11002900    1  * 12 word format
11002901    0.0   10.0   10.0   0.0   0.0   0.0   0.0   1.0
+           0.0   -0.5   1.0    12
* heat structure of channel 1 pressure tube
*
11102000    12    2    2    1    0.05190
11102100    0   1
11102101    1    0.056332
11102201    4   1
11102301    0.0  1
11102400    0
11102401    570.0   2
11102501    100010000    10000   1   1   47.0535  12
11102601    0            0       0   1   47.0535  12
11102501    100010000    10000   1   1   1.00     12
11102601    0            0       0   1   1.00     12
11102701    0   0.0   0.0   0.0   12
11102801    0.0   10.0   10.0   0.0   0.0   0.0   0.0   1.0   12
11102901    0.0   10.0   10.0   0.0   0.0   0.0   0.0   1.0   12
*
*=====================================================
*
*   heat structure thermal property data
*
*=====================================================
*
20100100    c-steel                    * carbon steel
20100200    tbl/fctn   1   1           * stainless steel
20100300    tbl/fctn   1   1           * uo2
20100400    tbl/fctn   1   1           * zircaloy
20100500    tbl/fctn   1   1           * inconel-800
20100600    tbl/fctn   1   1           * gap
*
*
*-
*  stainless steel property
*-
*           temperature  conductivity
*
20100201    273.15       12.98
20100202    1199.82      25.1
*
*           temperature  heat capacity
*
20100251    273.15       3.83e6
20100252    366.5        3.83e6
20100253    477.59       4.19e6
20100254    588.59       4.336e6
20100255    699.82       4.504e6
20100256    810.93       4.639e6
20100257    922.04       4.773e6
20100258    1144.26      5.076e6
20100259    1366.5       5.376e6
20100260    1477.59      5.546e6
*
*-
* UO2 Thernal Conductivity
*-
*           Temp.     Thermal Conductivity
*
20100301  2.7315e2  8.44
20100302  4.1667e2  6.46
20100303  5.3315e2  5.782385
20100304  6.99817e2 4.633177
20100305  8.66483e2 3.880307
20100306  1.03315e3 3.357625
20100307  1.08871e3 3.155129
20100308  1.19982e3 2.983787
20100309  1.28315e3 2.836674
20100310  1.36648e3 2.713792
20100311  1.53315e3 2.521680
20100312  1.61648e3 2.448990
20100313  1.69982e3 2.391875
20100314  1.97759e3 2.289762
20100315  2.25537e3 2.307069
20100316  2.53315e3 2.433413
20100317  2.81093e3 2.661870
20100318  3.08871e3 2.994171
*-
```

```
*          Temp.    Thermal Conductivity
*-
20100351  2.7315e2  2.319427e6
20100352  3.23150e2 2.571985e6
20100353  3.73150e2 2.746357e6
20100354  6.73150e2 3.138694e6
20100355  1.37315e3 3.443844e6
20100356  1.77315e3 3.531030e6
20100357  1.97315e3 3.792588e6
20100358  2.17315e3 4.228518e6
20100359  2.37315e3 4.882412e6
20100360  2.67315e3 6.015829e6
20100361  2.77315e3 6.320980e6
20100362  2.87315e3 6.582538e6
20100363  2.97315e3 6.713317e6
20100364  3.11315e3 6.800503e6
20100365  4.69982e3 6.800503e6
*
*
*
*  Zircoly Thermal Property
*
20100401  273.0   12.5
20100402  380.4   13.6
20100403  469.3   14.6
20100404  577.6   15.8
20100405  685.9   17.3
20100406  774.8   18.4
20100407  872.0   19.8
20100408  973.2   21.8
20100409 1073.2   23.2
20100410 1123.2   25.4
20100411 1152.3   24.2
20100412 1232.2   25.5
20100413 1331.2   26.6
20100414 1404.2   28.2
20100415 1576.2   33.0
20100416 1625.2   36.7
20100417 1755.2   41.2
20100418 2273.2   55.0
*
20100451  300.0  1.841e6
20100452  400.0  1.978e6
20100453  640.0  2.168e6
20100454 1090.0  2.456e6
20100455 1093.0  3.288e6
20100456 1113.0  3.865e6
20100457 1133.0  4.028e6
20100458 1153.0  4.709e6
20100459 1173.0  5.345e6
20100460 1193.0  5.044e6
20100461 1213.0  4.054e6
20100462 1233.0  3.072e6
20100463 1243.0  2.332e6
20100464 1477.0  2.332e6
*
* Constant value for Inconel-800
*
20100501      47.1
20100551       3.688e6
*
* Constant value for Gap
*
20100601       0.278
20100651     363.51
*
*
* total thermal power = 2111.5MW (4 loops)
20205000     power
20205001      -1.0         531.875e+6
20205002       0.0         531.875e+6
20205003       20000.0     531.875e+6
*
*
* dacay thermal power = 2111.5MW x 0.1 % (4 loops)
20205000     power
20205001      -1.0         50.0e+4
20205002       0.0         50.0e+4
20205003       20000.0     50.0e+4
*
20205001      -1.0         20.e+4
20205002       0.0         20.e+4
20205003       20000.0     20.e+4
*
20500100 jg mult 1.0 0.0  1
20500101 voidg 100060000  velg 100060000
20500200 jf mult 1.0 0.0  1
20500201 voidf 100060000  velf 100060000
```

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11. ABSTRACT *(200 words or less)*

The main purpose of this study is to develop a thermal hydraulic auditing analysis code for CANDU reactor by extending the model of current RELAP5/MOD3, which have been used for a long time as an auditing analysis took of Light Water Reactors (LWR). The major thermal hydraulic phenomena for the key CANDU events and the modeling limitation of the current RELAP5/MOD3 for CANDU applications are based on the previous study on the applicability of RELAP5 code to the CANDU-type plants. The seven models are improved: the CANDU fuel channel heat transfer model; the horizontal flow regime model; the digital control model; ANS94-4 decay heat model; Moody critical model; motor operative valve model; and pressurizer spray model. The models are improved and developed on generic base, thus, they also could be applicable to PWR. Especially, the plutonium contribution to decay heat can be considered by the ANS94-4 decay heat model. The Moody critical flow model using a heavy water property can provide an additional capability to evaluate the conservative break flow in CANDU system. Simulation of different rate of opening and closing the motor valve is now possible when calculating the liquid relief valve behavior during transient. And the new pressurizer spray model can be used for evaluating the droplet size effect on the condensation. All of those improvements are verified through some assessments with simple conceptual problems and Marviken critical flow test. The new code is based on the RELAP5/MOD3.2.2 gamma version, and written in FORTRAN 90 language.

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